



Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

1967

Tide-level and bottom-friction effects on wave refraction as determined by numerical wave refraction procedures

Farrell, Charles Augustus, Jr.

Monterey, California. Naval Postgraduate School

<http://hdl.handle.net/10945/13295>

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun



Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>

NPS ARCHIVE

1967

FARRELL, C.

TIDE-LEVEL AND BOTTOM FRICTION EFFECTS ON
WAVE REFRACTION AS DETERMINED BY
NUMERICAL WAVE REFRACTION PROCEDURES

CHARLES AUGUSTUS FARRELL

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 95040

TIDE-LEVEL AND BOTTOM-FRICTION EFFECTS
ON WAVE REFRACTION AS DETERMINED BY
NUMERICAL WAVE REFRACTION PROCEDURES

by

Charles Augustus Farrell, Jr.
Lieutenant, United States Navy
B.S., Naval Academy, 1961

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
June 1967

NPS ARCHIVE
1967
FARRELL, C

ABSTRACT

Numerical wave refraction programs permit a detailed study of the transformation of wave energy as waves move from deep water to shallow water. By eliminating the subjectivity that is present with hand drawn diagrams the effect of small variations in the initial assumptions and wave conditions can be investigated. The effects on wave refraction of tide level changes and bottom friction are investigated here. It is demonstrated that a uniform increase in water level as would be caused by tidal fluctuations can cause a significant change in the wave refraction pattern for a given nearshore region. A computing procedure is developed to permit numerical refraction programs to account for bottom friction. The reduction in wave height caused by bottom friction depends primarily on bottom slope; this relation is shown in tabular and graphical form.

TABLE OF CONTENTS

Section	Page
1. Introduction	11
2. Computer Program	13
Depth Grid	13
Input Data	13
Computer Output	15
Computer Operations	15
3. Effect of Tide Level Changes on Wave Refraction	17
Differences in Shoaling Factor, Wave Speed, and Ray Curvature at Specific Depths	17
Differences in Wave Refraction Patterns for Specific Locations	21
4. Bottom Friction Effect on Wave Height	30
Introduction to Bottom Friction	30
Computing Procedures	31
Results of Bottom Friction Computations	33
5. Conclusions	38
6. Recommendations	39
7. Bibliography	41
8. Appendix 1 Computer Program	42
9. Appendix 2 Sample Input and Output	56
10. Appendix 3 Summary of Equations	59

LIST OF TABLES

Table		Page
I.	H/H ₀ ratio at low tide and high tide for specific coastal locations near Point Sur, California.	23
II.	H/H ₀ ratio at high tide and low tide for specific coastal locations near Eastern Head, Maine.	23
III..	Wave height reduction due to bottom friction as determined by Putnam and Johnson and by the numerical wave refraction program.	34
IV.	Percent reduction of wave height for various values of TIME.	35
V.	Wave height reduction for bottom slopes of 1:100 to 1:400 and wave periods of 8 to 16 seconds.	35

LIST OF ILLUSTRATIONS

Figure		Page
1.	Effect on wave speed of varying tide levels for 8-16 second waves.	18
2.	Effect on ray curvature of varying tide levels for 8-16 second waves.	20
3.	Low tide refraction diagram for Big Sur, California.	24
4.	High tide refraction diagram for Big Sur, California.	25
5.	Low tide refraction diagram for Big Sur, California.	26
6.	High tide refraction diagram for Big Sur, California.	27
7.	Low tide refraction diagram for Eastern Head, Maine.	28
8.	High tide refraction diagram for Eastern Head, Maine.	29
9.	Expected wave height reduction at breaking point due to bottom friction for bottom slope of 1:10 to 1:400.	37

TABLE OF SYMBOLS

A	approach angle of wave ray
β	ray separation in shallow water divided by ray separation in deep water
C	wave velocity
C_0	deep water wave velocity
f	dimensionless friction coefficient for the bottom.
FK	curvature of ray
g	acceleration due to gravity
H	wave height at position x
H_0	deep water wave height
H_1	wave height at position x_1
H/H_0	wave height at position x divided by deep water wave height
HHFR	wave height at position x, when bottom friction is included, divided by deep water wave height
K_f	wave height reduction factor due to bottom friction alone
K_r	refraction factor
K_{fr}	combined friction and refraction factor
K_s	direct shoaling factor
L	wave length
L_0	deep water wave length
s	wave ray
T	wave period
x	distance measured along the wave ray in the direction of propogation of the waves
Δx	$x - x_1$
π	3.1416...

Note: All values are assumed to be in the English System of Units.

1. Introduction

Preparing accurate wave refraction diagrams is a necessary first step in many coastal engineering and amphibious operations. The advent of the numerical wave refraction programs [Griswold (1963), Stoupe (1966), Wilson (1966)] has considerably reduced the time required to construct a wave refraction diagram. The speed of the computer operations permits more parameters to be included in the calculations and improves the accuracy of the output. Of equal importance is the fact that numerical products provide a completely objective basis for evaluating the cumulative effect of various assumptions on wave refraction.

The present study has investigated the effects of tide-level changes and bottom friction on wave-refraction patterns for several environments. The investigation first compared the wave refraction programs of Griswold (1963), Stoupe (1966), and Wilson (1966). Since there was no way available to the author to compare program accuracy on an absolute scale, the comparison was based on method of computation, simplicity of use, and presentation of results.

The program written by Stoupe was considered to have the most potential and was chosen for use in this investigation. The major advantages of Stoupe's program are these:

- (1) The program uses water depth directly as the interpolation surface for evaluation of wave speed, thereby limiting the number of computations and increasing the program versatility.
- (2) The program uses a second-order non-linear differential equation to determine the refraction coefficient at each point along the ray. Thus, the wave height at each point can be computed.

(3) The program uses constant time steps in the computation rather than constant distance steps. This reduces the distance between computations as the shoreline is approached. Thus for the same number of computer operations a greater percentage of computations are in the shallowest area where refraction, friction, etc., are most important, and are changing rapidly.

(4) The program includes a graphical output that plots the wave orthogonals, wavecrests and the shoreline.

The following modifications were made to Stoupe's program:

(1) The program was made to recycle, permitting more effective use of computer time when more than one diagram is to be constructed.

(2) Provision was made to add a constant value to the depth field to investigate tide level effects.

(3) A subroutine was added to account for bottom friction in the computation of wave height.

2. Computer Program.

Depth grid.

The first step in the utilization of this program is the construction of a grid of water-depth values for the desired area. The grid must be sufficiently large so that the starting point of all rays to be followed is in deep water, i.e., the ratio of water depth to deep water wave length (d/L_0) is greater than 0.5. By convention the x-axis is positive increasing toward the shore while the y-axis is positive to the left of the x-axis. The grid interval is selected so that the bottom contours are reasonably parallel to one another within a given square.

In constructing the depth grid it is advantageous to record the average value of all depths within that grid square, rather than the value of water depth at the intersection point. This procedure tends to correct for small variations in the depth of water within the depth grid without necessitating the use of a smaller grid size. All actual depths are made positive; extrapolated depth values are continued on land for two grid units from the shoreline and are made negative. Beyond two grid units from the shoreline any arbitrary negative depth may be used. For depths on the shoreline itself zero is used.

To reduce the time required to obtain the depth grid a clear plastic overlay with a black dot at each grid intersection point was prepared by initially locating the grid dots on white paper and producing a viewfoil transparency with an Ozalid copier, Model 400.

Input data.

Stouppé's order of data input was modified to permit the program to recycle. The present data deck consists of three sections. The first section contains only the value of MM and NN which designate the number of points in the depth grid in the x and y directions respectively. The

second section contains the water depth grid. These values are arranged so that the computer reads all the y values for each successive x-grid position. Water depths are read in fathoms and are converted to feet within the computer program. The last section contains one card for each set of input parameters for which it is required to construct a wave refraction diagram. The input parameters include:

X,Y: The grid position for the starting point of the first ray (feet). All starting rays must be more than two grid intervals in distance from the edge of the depth grid.

FCF: The coefficient of bottom friction.

TIDE: The tide level, in feet, above chart depth for which computation is required. This value is subtracted from the depth grid after each refraction pattern is completed.

HINT: The deep water wave height (feet). This is required for the friction subroutine.

T: The initial wave period (seconds).

A1: The initial wave angle (degrees). The smaller angle measured between the positive Y direction and the initial wave crest. The angle is made negative if the slope of the wave crest is negative.

NOR: The number of rays to be followed.

TIME: The time interval between computations for advancing of the wave front (seconds).

DIST: The distance between rays (feet).

GRID: The grid interval (feet).

This order of data input permits wave refraction diagrams to be computed for many combinations of input variables while requiring the computer to assemble the program and read the depth field only once.

Computer output.

The output from the computer consists of both a printed output and a graphical output. The printed output variables are these:

X,Y: The x and y coordinates for a given wave crest and ray number (yards).

COREFR: The coefficient of refraction (K_r) for the wave at the point x,y.

HHO: The ratio of wave height to deep water wave height neglecting bottom friction.

HHFR: The ratio of wave height to deep water wave height when bottom friction is included.

NGO: Indicates that the ray has terminated (1), or it is continuing (2).

DEPTH: The water depth for grid position X and Y (feet).

The graphical plot of wave crests is programmed for the Calcomp 160 system utilizing the DRAW subroutine programmed by J. R. Ward for the Fortran 60 system. See Appendix II, Stoupe (1966), for subroutine listing. The first and each succeeding third wave crest are plotted. The zero water depth points are used for contouring the shoreline on the graph.

Appendix 2 contains a sample of the printed and graphical output for Monterey Bay, California.

Computer operations.

Since the details of the computer operations are discussed by Stoupe (1966), only the main features will be discussed here. The formulas used in the computations are listed in Appendix 3.

The water depth at the first point is computed by fitting the closest nine grid-point depths to a quadric surface by the least-squares method. An iterative procedure is then used to solve for wave velocity. It is assumed here that wave velocity is a function of water depth and period only.

The wave ray is then moved to the next point by solving for the ray curvature and projecting the ray forward a distance equal to the product of the wave speed for the point multiplied by TIME. At this new point the value of ray separation (β), coefficient of refraction (K_r), shoaling factor (K_s), H/H_0 , and HHFR are calculated.

This procedure is repeated until all orthogonals have been advanced one time interval. The new wave crest is plotted and the entire procedure is repeated until all orthogonals have either gone off the grid or reached the shoreline.

3. The Effects of Tide Level Changes on Wave Refraction Patterns.

Differences in shoaling factor, wave speed, and ray curvature at specific depths.

The effect on wave refraction of a uniform increase in water depth caused by tide level changes is cumulative and is dependent on the bottom depth contours. Therefore, to evaluate the effect properly, a wave ray must be followed along its entire distance from deep water to the shore. However, by calculating the value of shoaling factor (K_s), wave speed (C), and ray curvature (FK) at both high tide and low tide it is possible to evaluate the order of magnitude of the differences in the basic parameters of wave refraction caused by tide level fluctuations.

The value of K_s , C , and FK were calculated initially for 25, 50, and 100 foot water depths; second calculations were made for a water depth equal to the initial water depth plus a tide level increase of 6, 10, and 16 feet. To evaluate these differences on a relative scale a percent difference was calculated by using the formula:

$$\% \text{ difference } X = \left| \frac{X_{HT} - X_{LT}}{X_{HT}} \right| \quad (1)$$

where

X = variable representing C , K_s , or FK

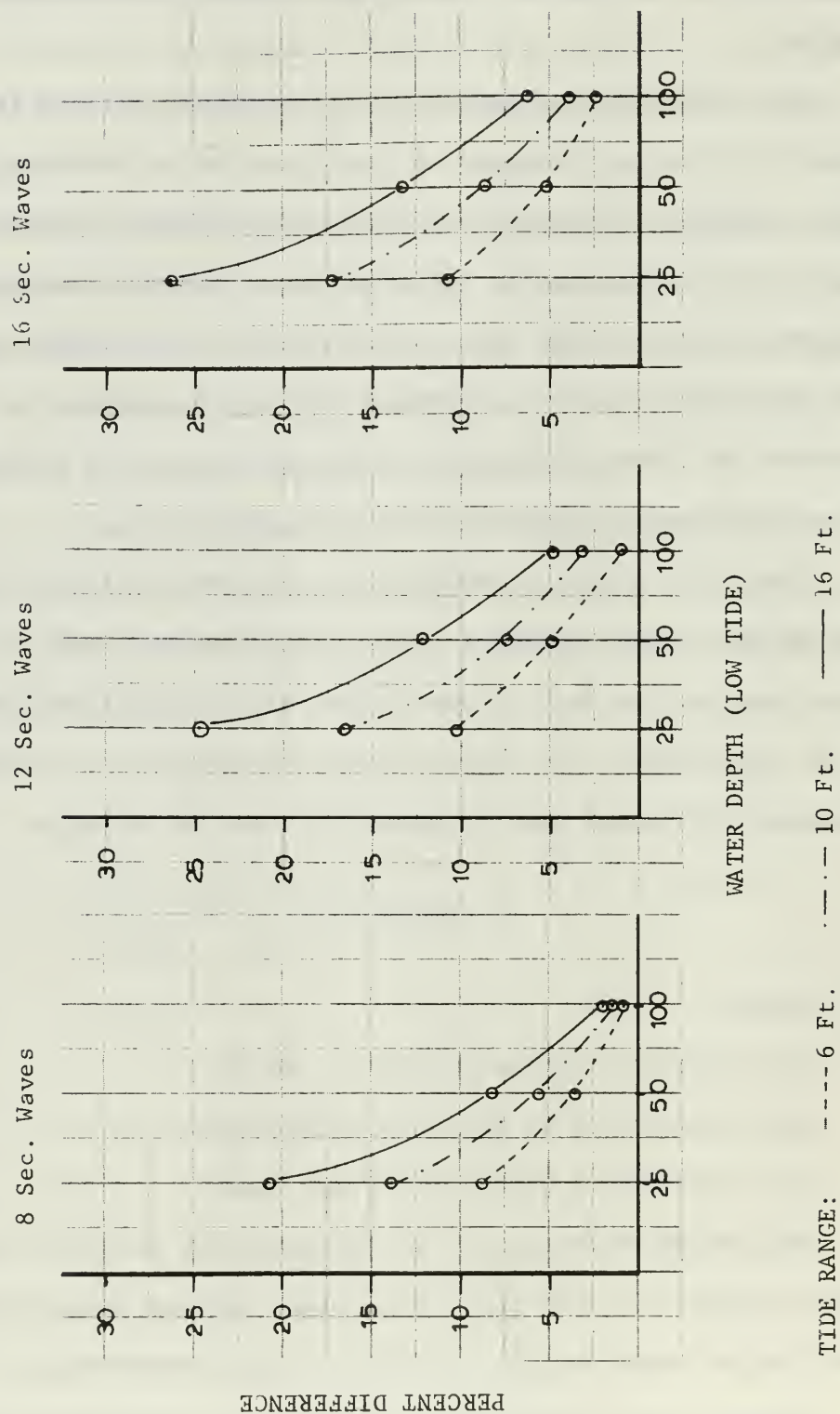
X_{ht} = value of X at high tide water depth

X_{lt} = value of X at low tide water depth.

The percent difference of K_s was generally small and under certain conditions went to zero (for those values associated with the inflection point in the curve when K_s is plotted against water depth).

Figure 1 shows the percent difference in wave speed corresponding to the low tide water depth for a specific tide range and wave period.

Figure 1. EFFECT ON WAVE SPEED OF VARYING TIDE LEVELS FOR 8-16 SECOND WAVES.



It is apparent that the difference is often greater than 10 percent and increases with increasing wave period, increasing tide range and decreasing low tide water depth.

The values of ray curvature (FK) were determined using the equation:

$$FK = \frac{1}{C} \left[\sin A \frac{\partial C}{\partial X} - \cos A \frac{\partial C}{\partial Y} \right] \quad (2)$$

where

A = approach angle

$\frac{\partial C}{\partial X}$, $\frac{\partial C}{\partial Y}$ = derivative of wave speed in the X and Y directions respectively.

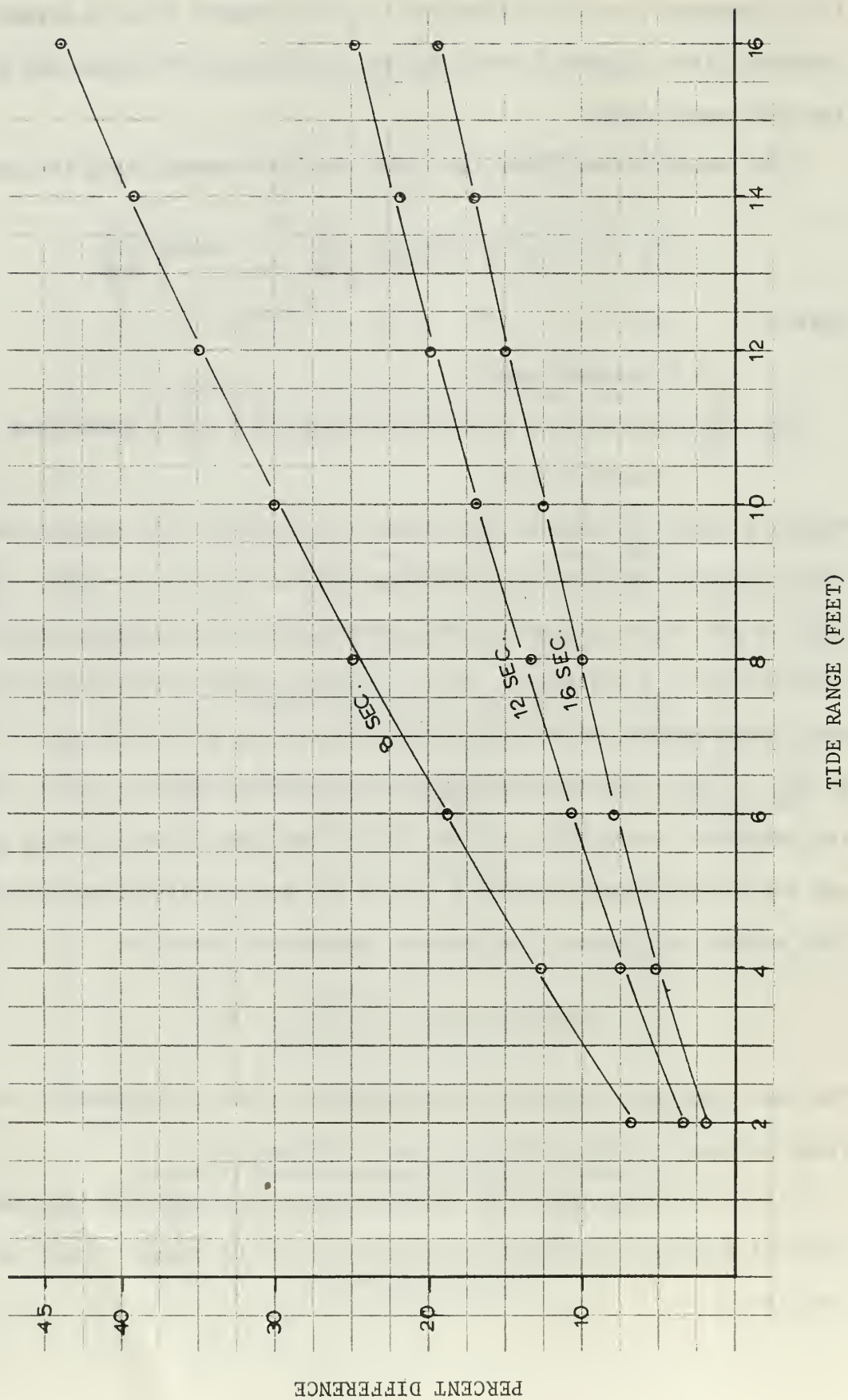
Figure 2 shows the percent difference in FK versus tide range (computed using equation (2) with the following initial values: $A = 30^\circ$, $\frac{\partial C}{\partial Y} = 0$, $\frac{\partial C}{\partial X} = \Delta C$ for a twenty foot change in water depth starting with an initial depth of 100 feet). The values of percent difference plotted are representative of the percent difference for all values of A, $\frac{\partial C}{\partial X}$, $\frac{\partial C}{\partial Y}$, and water depth; this occurs because the terms inside the brackets in equation (2) have nearly the same value for high tide and low tide and tend to cancel out in the percent difference calculation. This reduces the percent difference calculation for FK to

$$\% \text{ difference FK} = \left| \frac{C_{LT} - C_{HT}}{C_{HT}} \right| \quad (3)$$

The fact that the difference calculation is primarily dependent on tide range and wave speed is clearly shown in Figure 2.

It is concluded that the change between high tide and low tide in a refraction pattern is primarily determined by the change in ray curvature (FK).

Figure 2. EFFECT ON RAY CURVATURE OF VARYING TIDE LEVELS FOR 8-16 SECOND WAVES



Difference in wave refraction patterns for specific locations.

To investigate the combined effect of the changes in C , K_s and FK caused by a uniform increase in water depth, wave refraction diagrams were constructed for several locations using both the low tide water depths and the high tide water depths.

The first area considered was the California coast near Big Sur, between latitude $36^{\circ} 14' 30''$ and latitude $36^{\circ} 17' 42''$. This area was chosen because eight-second waves arriving on the coast will be refracted by the offshore bar (shown by the shaded area in Figures 3 and 4) at low tide but not at high tide.. Thus tide level changes will cause selective refraction by the offshore bar. Figure 3 shows the refraction pattern for 8 second waves approaching from 270 degrees at low tide; Figure 4 shows a different pattern for the same condition at high tide.¹

Figures 3 and 4 show two major differences in the refraction pattern. First, orthogonals 6 and 7 cross approximately halfway to shore at low tide but they do not cross at high tide.² Secondly, at low tide there is a convergence of wave orthogonals at Point A; this convergence is not present at high tide.

¹To make the changes in the orthogonal pattern more prominent Figures 3-8 are plotted with an expanded ordinate scale. Also, the computer was not used to contour the wave crests but rather the wave orthogonals were contoured manually; the shoreline was indicated by a triangle plotted whenever water depth was zero. TIME equalled 30 seconds for all diagrams.

²Interpretation of the effect of crossed orthogonals is beyond the scope of this paper. In this discussion we will only be concerned with the difference in ray paths between low tide and high tide.

Table 1 shows the value of the wave-height ratio (H/H_0) computed at four wave crests before the shoreline is reached for specific points along the coast. This table clearly shows that the value of wave height can be considerably different at low tide and high tide.

Figures 5 and 6 represent the same initial conditions as Figures 3 and 4 except that the initial wave direction is from 310 degrees. The change in the orthogonal pattern is clear. It is noted that in Figures 3 and 4 the primary change in the orthogonal pattern (between low tide and high tide) is in the vicinity of points B and C, whereas in Figures 5 and 6 the greater change occurs near Point A.

Wave refraction diagrams were also computed for the coast of Maine between latitude $44^{\circ} 39' 35''$ and latitude $44^{\circ} 44' 45''$. This area was chosen in order to determine if the combination of a large tide range (16 feet) and deep water depths (greater than 200 feet a short distance from the shoreline) would cause a change in the refraction pattern. Figures 7 and 8 show the refraction patterns for 16-second waves arriving from 070 degrees at low tide and high tide. The difference in refraction patterns is evident. Table 3 shows the H/H_0 ratios (calculated at four wave crests before reaching the shoreline) for specific locations at low-tide and high-tide conditions.

In total, about 20 sets of refraction patterns were analyzed and it appears impossible to predict what changes in wave height and refraction patterns will occur as the result of tide level changes. The only generalization that can be made is that the curvature of an orthogonal is generally greater at low tide than at high tide. It is concluded that precise water-level information, including tide state, should be incorporated into wave refraction procedures.

TABLE I

H/H₀ RATIO AT LOW TIDE AND HIGH TIDE FOR SPECIFIC COASTAL LOCATIONS
NEAR POINT SUR, CALIFORNIA.

LOCATION (SEE FIG. 3)	H/H ₀ RATIO	
	LOW TIDE	HIGH TIDE
A	1.1	1.2
B	1.3	.9
C	3.1	1.7
D	.8	.8

TABLE II

H/H₀ RATIO AT LOW TIDE AND HIGH TIDE FOR SPECIFIC COASTAL LOCATIONS
NEAR EASTERN HEAD, MAINE.

LOCATION (SEE FIG. 7)	H/H ₀ RATIO	
	LOW TIDE	HIGH TIDE
A	2.8	3.3
B	1.0	1.2
C	.7	.8
D	.7	.7

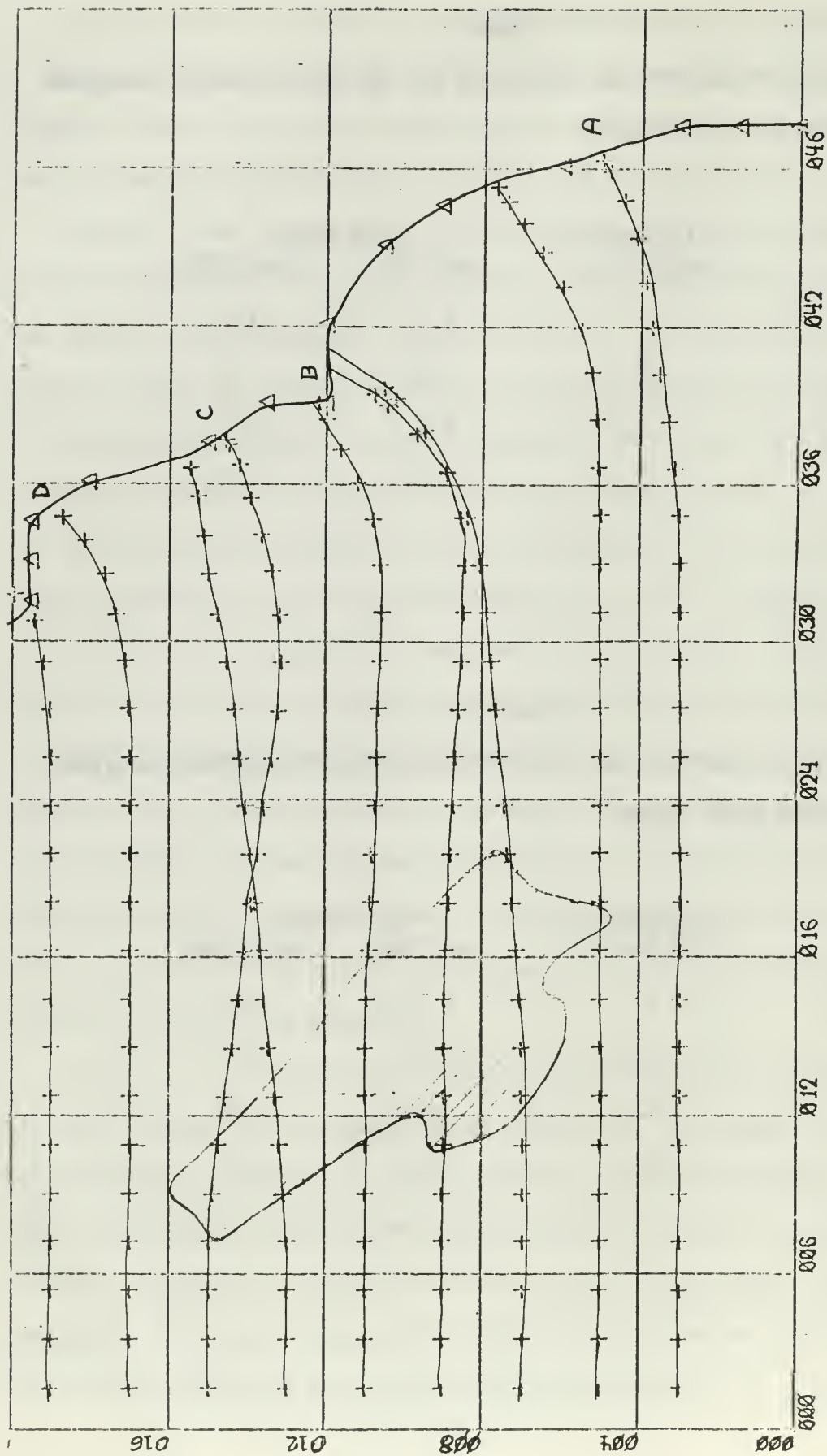


Figure 3. Low tide refraction diagram for Big Sur, California. $T = 8$ sec. $A = 270^\circ$. $\text{TIME} = 30$ sec.
Latitude $36^\circ 14' 30''$ to latitude $36^\circ 17' 42''$. East-West Scale 6000 Ft./inch. North-South scale 4000 Ft./inch.

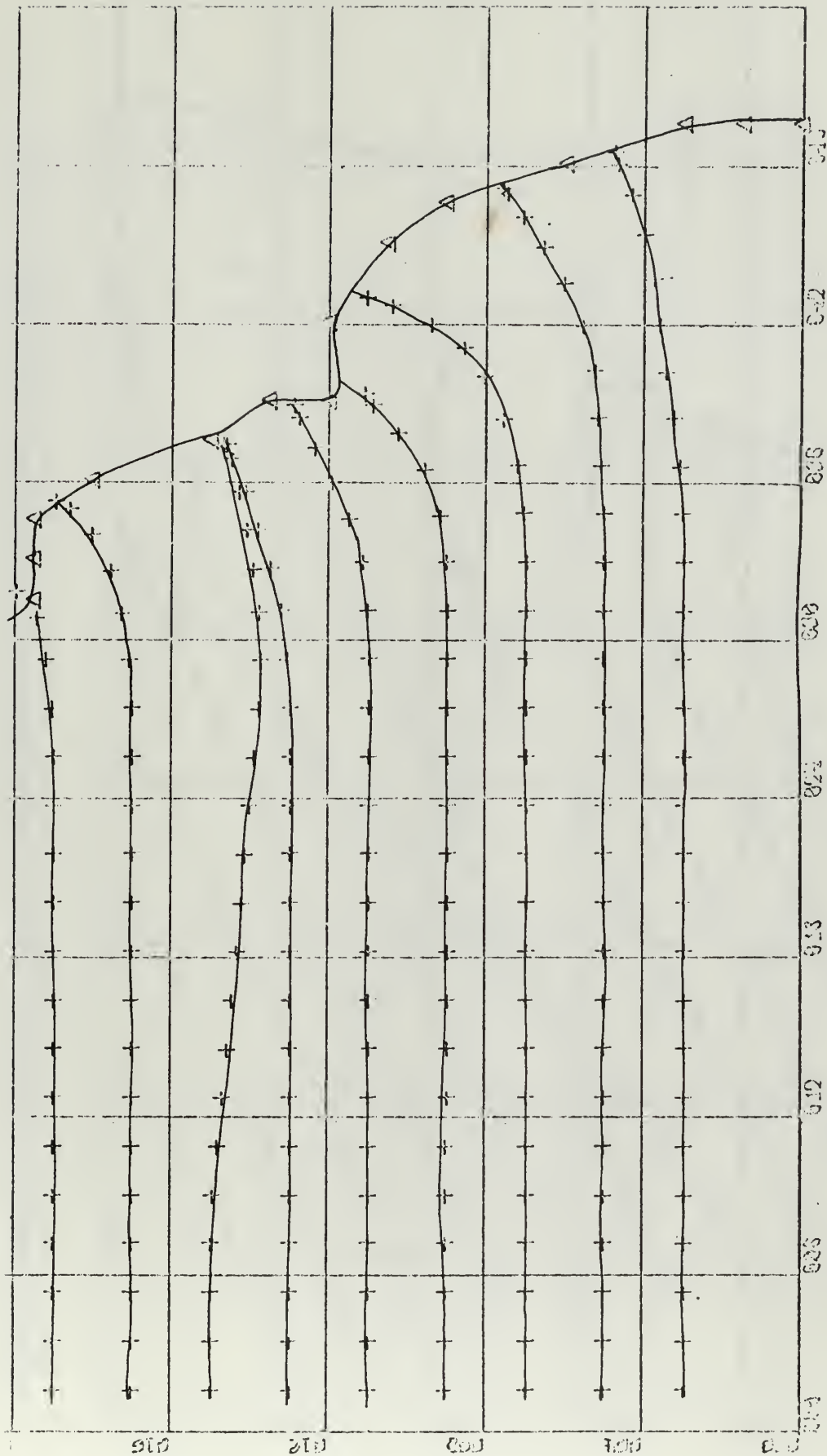


Figure 4. High tide refraction diagram for Big Sur, California. $T = 8$ sec. $A = 270^\circ$. TIME = 30 sec. Latitude $36^\circ 14' 30''$ to $36^\circ 17' 42''$. East-West scale 6000 Ft./inch. North-South scale 4000 Ft./inch.

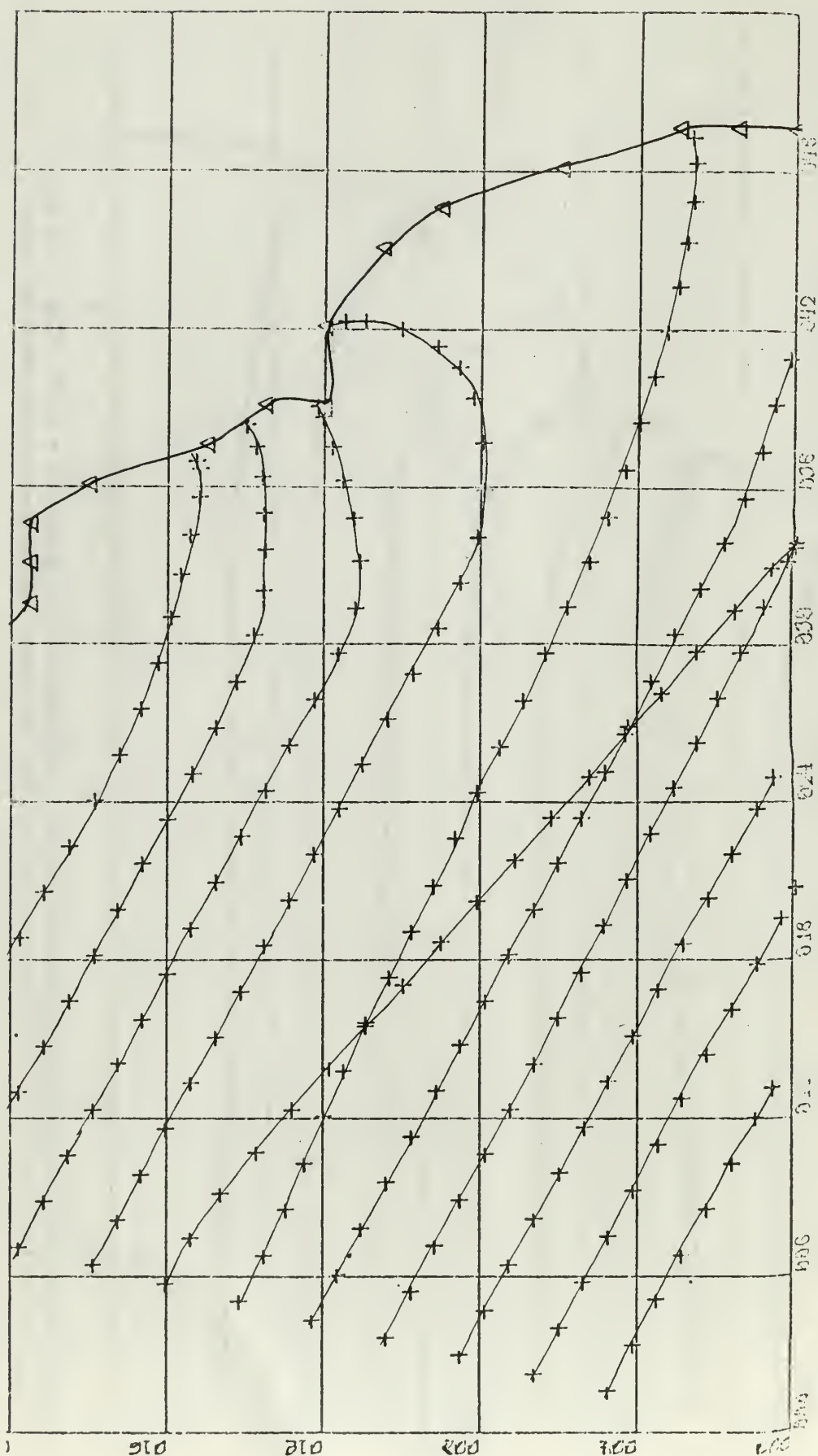


Figure 5. Low tide refraction diagram for Big Sur, California. $T = 8$ sec. $A = 3100$. TIME = 30 sec.
Latitude $36^{\circ}14'30''$ to $36^{\circ}17'42''$. East-West scale 6000 Ft./inch. North-South scale 4000 Ft./inch.

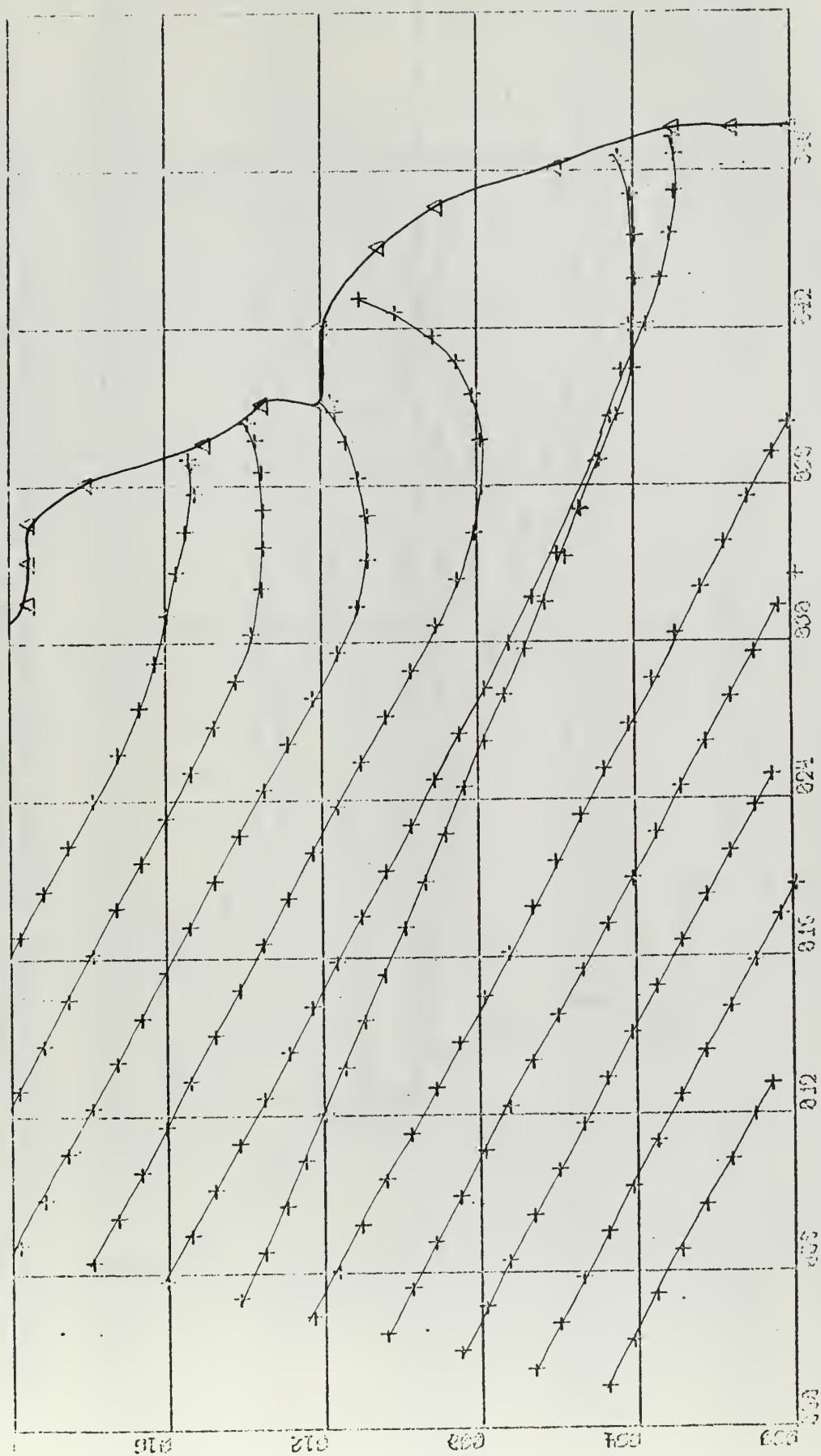


Figure 6. High tide refraction diagram for Big Sur, California. T = 8 sec. A = 310°. TIME = 30 sec.
Latitude 36°14'30" to latitude 36°17'42". East-West scale 6000 Ft./inch. North-South scale 4000 Ft./inch.

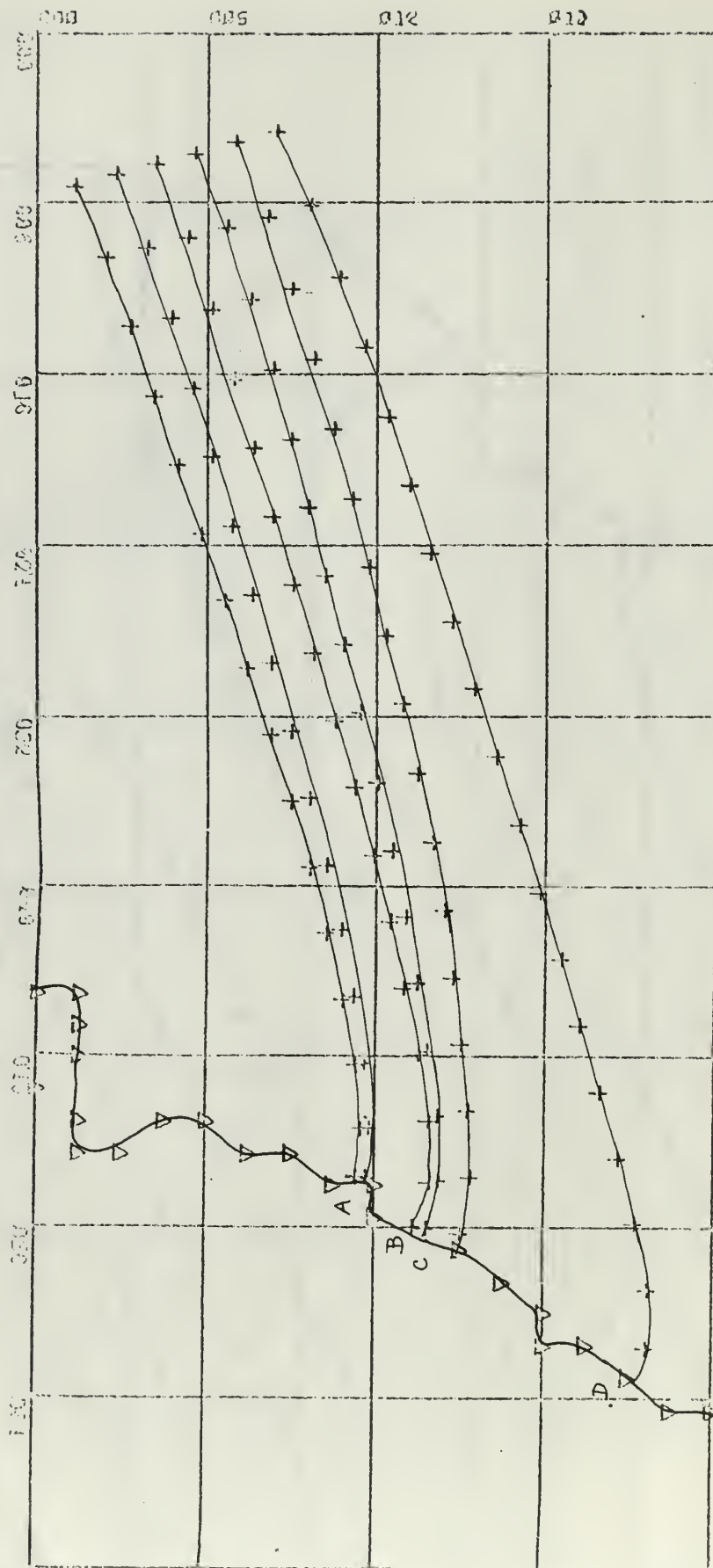


Figure 7. Low tide refraction diagram for Eastern Head, Maine. $T = 16$ sec. $A = 070^{\circ}$. TIME = 30 sec. Latitude $44^{\circ}39'35''$ to latitude $44^{\circ}44'45''$. East-West scale 8000 Ft./inch. North-South scale 6000 Ft./inch.

4. Bottom Friction Effects on Wave Height.

Introduction to bottom friction.

The present method for calculating wave height assumes that the propagation of energy between two adjacent orthogonals is conserved as the wave proceeds from deep water to shallow water. This implies that the addition of energy by surface winds, dissipation of energy by bottom friction or internal friction, and the reflection of energy by a steep slope are absent. In nature this is not the case - the wave energy between adjacent orthogonals may be changed by all of these means.

According to Lamb (1932), in fluids of small viscosity (such as sea water), the velocity of the wave and the relationship between depth, length, and period are unaltered by internal friction. This is based on the assumption of a sinusoidal wave form but the result appears to indicate a very slow rate of damping of all waves in deep water, which is in accord with the limited observations in nature (Putnam and Johnson, 1949).

At the sea bottom, however, friction can cause a loss of wave energy. It can be demonstrated both theoretically and experimentally that the particle velocities of shallow water waves are finite at the bottom and actually approach the theoretical orbital values at a short distance from the bottom. Therefore, a boundary layer in which mechanical energy is dissipated through the distortion of fluid elements must exist at the bottom. The effective roughness of a sandy bottom probably is determined by the size of the ripples in the sand rather than by the size of the sand grains. The ripple size, however, appears to be determined by the size and sorting coefficients of the sand in addition to the height and period of the wave and the depth of water.

Putnam and Johnson established the general magnitude for the dimensionless friction coefficient for the sea bottom to be 0.01. (This value was computed assuming initial conditions of 12 second waves, 4 feet high, traveling over a sandy beach with a ripple spacing of 5 inches.) Putnam and Johnson point out that since the friction factor only enters the equations for wave height to the first power, the friction factor could change by ± 50 percent without appreciably changing the order of magnitude of wave-height reduction.

Based on the following assumptions Putnam and Johnson were able to develop a procedure to calculate wave height when bottom friction is included.

- (1) The oscillatory motion at the bottom is sinusoidal and corresponds to the wave theory based on small amplitudes.
- (2) The friction coefficient does not vary with velocity and is approximately independent of water depth. This assumption amounts to choosing an average friction factor for the entire region over which the sea bottom affects the wave motion.
- (3) Perpendicular flow at the bottom resulting from percolation in the bottom material is negligibly small.
- (4) The sea bottom has a constant upward slope from offshore to the breaker point.

Computing procedures.

Bretschneider and Reid (1954) extended the original work of Putnam and Johnson and developed new equations to solve for wave height which included simplified equations for the special cases of constant water depth and constant bottom slope.

Bottom friction is of importance only on gently sloping beaches and in shallow water; thus it is possible, when using numerical wave refraction procedures, to calculate the reduction to wave height due to bottom friction by making the assumption that the water depth is constant between successive computations along the ray path from deep water to the shoreline.

The wave height at each step is computed by the equation

$$H = H_1 \left[1 - \{ (1 - K_{f_1}) + (1 - K_{f_2}) + \dots + (1 - K_{f_m}) \} \right] \quad (4)$$

where

H_1 = the calculated wave height, neglecting bottom friction, for the point;

K_{f_n} = the refraction factor between point $n-1$ and n .

The coefficient of friction (K_f) is calculated by the equation (from Bretschneider and Reid)

$$K_f = \frac{1}{\frac{A' \phi_f}{K_s} \Delta x + 1} ; \quad (5)$$

$$A' = \frac{f H_1}{T^4} ;$$

$$\phi_f = \frac{64 \pi^3}{3g^2} \left(\frac{K_s}{\sinh \frac{2 \pi d}{L}} \right)^3 ;$$

K_s = direct shoaling factor;

Δx = incremented distance.

K_f is computed at each ray point with Δx equal to the distance along the wave ray between point n and $n + 1$. It is assumed in the computations that the water depth between point n and $n + 1$ is constant and equal to the depth at point n .

Results of bottom friction computations.

The accuracy of the approximation that water depth is constant can be seen by a comparison of wave height obtained by this procedure to the wave height obtained by the more sophisticated and accurate procedure used by Putnam and Johnson. This comparison is shown in Table 3 (computed for wave period = 12 seconds, bottom slope = 5 feet). The comparison is very favorable along the entire distance of travel from the point that the wave first feels bottom to the breaking point. The difference is certainly within the order of magnitude of the error introduced by other assumptions. The difference in values is caused by the approximation to constant depth steps in the calculating procedure.

Since this program uses constant time steps in moving each ray point toward the shoreline, the horizontal distance over which depth is assumed constant can be reduced by shortening the computing time interval (TIME). Table 4 shows the reduction (in percent) of wave height at the breaking point for different computing time intervals (with wave and bottom conditions the same as shown for Table 3 above). As expected, there is a slight increase in wave height reduction as the computing interval is decreased. It can be concluded that the value of TIME will affect the wave heights calculated by this procedure, but the effect is small.

Realizing the limitations imposed by the initial assumptions of Putnam and Johnson and the calculating procedure employed here, the computer program was used to compute the wave height (with bottom friction included) for varying initial periods and bottom slopes. The results are shown in Table 5. (In arriving at these results it was assumed that the initial wave height was 5 feet and the friction coefficient was 0.01.) The reduction in wave height (in terms of percent of the wave height

TABLE III

WAVE HEIGHT REDUCTION DUE TO BOTTOM FRICTION AS DETERMINED BY PUTNAM
AND JOHNSON AND BY THE NUMERICAL WAVE REFRACTION PROGRAM.

$T = 12$ sec. $H_0 = 5$ FT. $f = .01$ TIME = 30 sec.

Bottom slope = 1:300 Breaking depth = 11.5 Ft.

DISTANCE FROM WHERE $h = L_0/2$ TO BREAKING POINT	PERCENT REDUCTION WAVE HEIGHT	
	FARRELL CONSTANT DEPTH STEPS	PUTNAM & JOHNSON CONSTANT SLOPE
PCT	PCT	PCT
0.0	0.0	0.0
50.0	0.0	0.0
62.0	0.2	0.2
70.3	0.4	0.4
80.5	1.0	1.1
86.8	1.9	2.1
90.8	3.1	3.2
93.0	4.2	4.5
95.0	6.0	6.2
97.1	8.7	9.3
100.0	18.5	20.8

TABLE IV

PERCENT REDUCTION IN WAVE HEIGHT FOR VARIOUS VALUES OF TIME

TIME (SEC)	WAVE HT. REDUCTION (%)
20	19.0
30	18.5
40	18.0
50	17.0

TABLE V

WAVE HEIGHT REDUCTION FOR BOTTOM SLOPES OF 1:100 to 1:400 AND WAVE PERIODS OF 8 to 16 SECONDS (PERCENT)

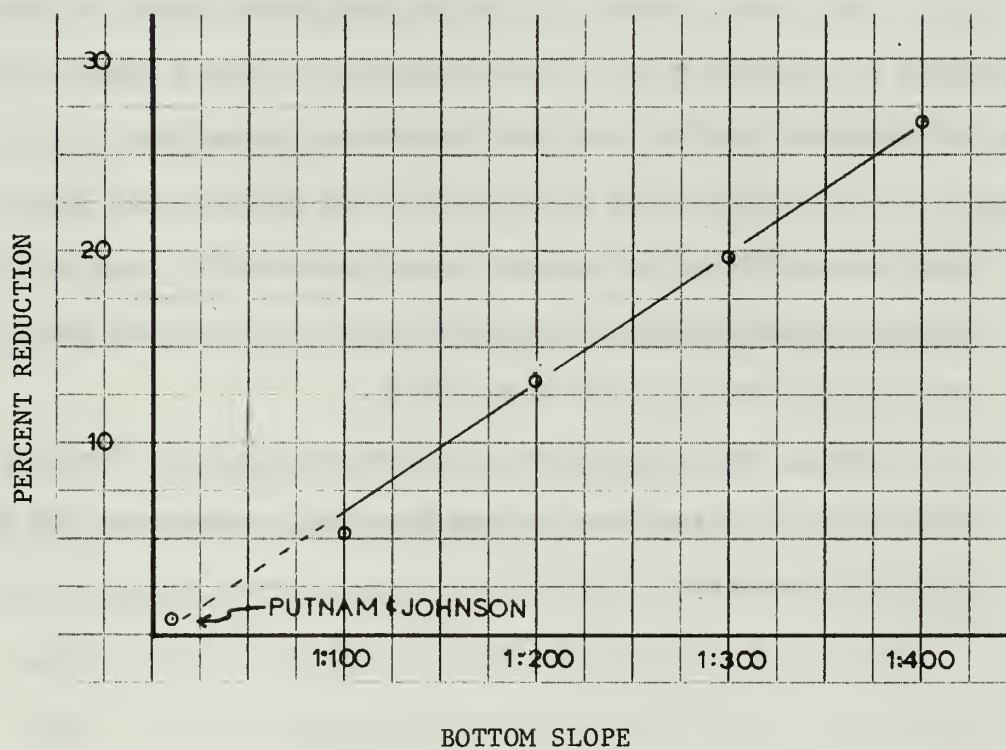
WAVE PERIOD	BOTTOM SLOPE			
	1:100	1:200	1:300	1:400
8	5.4	14.0	21.5	28.6
10	5.2	13.5	20.2	27.0
12	5.2	13.0	18.5	24.8
16	5.0	12.2	18.2	24.2
AVERAGE	5.2	13.2	19.6	26.9

without friction) is shown for the theoretical breaking depth (from H.O. 234). To obtain the percent reduction at the specific breaking depth, it was necessary to fit a smooth curve to the plotted points of wave height reduction at the three closest water depths and interpolate the wave height reduction at the breaking point.

Figure 9 shows the average reduction (for all periods from Table 5) of wave height versus bottom slope. The curve is extended by a dashed line to the reduction amount found by Putnam and Johnson for a 1:10 beach slope.

The quantitative value of Figure 9 is controlled by the input accuracy of the coefficient of friction, the initial assumptions and the computation procedure. However, Figure 9 does show, qualitatively, the effect of bottom slope on wave height reduction due to bottom friction. Figure 9 is considered sufficiently accurate to be used in surf forecasting on sandy beaches to provide a first approximation of wave height reduction due to bottom friction.

Figure 9. EXPECTED WAVE HEIGHT REDUCTION AT BREAKING POINT DUE TO BOTTOM FRICTION FOR BOTTOM SLOPES OF 1:10 to 1:400.



5. Conclusions.

The numerical approach to wave refraction is a powerful tool in that it eliminates human subjectivity and permits the refraction computations to account for more factors than is possible with hand drawn techniques.

A computer program that uses constant time intervals between computations has more suitability in accounting for the effects of friction, wind, reflection, etc., than a computer program that employs constant distance steps.

Tide level changes can have a significant effect on wave refraction. This is especially true in areas where there is a large tide range or an offshore bar that can cause selective refraction.

The changes shown by the tide level effects also point to the importance of having an accurate water depth grid. To avoid significant errors in the refraction pattern a great deal of care must be exercised in the preparation of the depth grid.

Bottom friction can and does have an effect on the wave height. The numerical refraction program provides a convenient way to account for this reduction.

6. Recommendations.

The course of this investigation has permitted a close look at wave refraction from many points of view. The numerical refraction program is capable of yielding wave refraction information with great speed and accuracy. (Computer time is approximately 5 minutes for a 20 ray diagram.) However, before the advantages of the computer product can be fully realized the author believes further investigations and improvements are needed in the areas of input data, computing procedures and field investigations.

The need for accurate depth information is essential to the computation of accurate refraction patterns. It is anticipated that the present efforts of the Naval Oceanographic Office and the Coast and Geodetic Survey in the area of color photography will improve the water depth information especially in areas where the bottom contours change considerably and in the shallow areas where it is difficult for hydrographic vessels to proceed.

The computer program can be expanded to account for more variables and to provide additional output information; in particular:

- (1) The program should account for the fact that in nature there usually exists a spectrum of wave periods and directions, rather than the single period and direction that is considered here.
- (2) For amphibious operations it would be advantageous if the program determined the breaking depth of the waves, printed out the height of the waves at the breaking point, and then contoured the breaking point on the output refraction diagram.

(3) Another desirable output for amphibious operations is a computer plot on the output diagram of the area where the wave height is a minimum, as this would be an ideal area to anchor large ships.

(4) The various subroutines should be checked to ensure that each section is providing comparable accuracy.

Field work is necessary to determine the value of the bottom friction factor for various type bottoms. This is essential before accurate wave height information can be obtained. Field investigations are also needed to determine the accuracy of the computer program; until now the numerical wave refraction procedures have been checked only by comparison with hand drawn results.

BIBLIOGRAPHY

1. Breakers and surf, principles in forecasting. U. S. Naval Hydrographic Office, Pub. 234, 1944.
2. Bretschneider, C. L. and Reid, R. O., Modification of wave height due to bottom friction, percolation, and refraction. Beach Erosion Board, Tech. Mem. 45, 1954.
3. Griswold, G. M., Numerical calculation of wave refraction. Journal of Geophysical Research, v. 68, 1963 : 1715-1723.
4. Griswold, G. M., and Nagle, F. W., Wave refraction by numerical methods. Mimeo Rept., U. S. Navy Weather Research Facility, 1962.
5. Lamb, H., Hydrodynamics, 6th Ed. Cambridge University Press, 1932.
6. Putnam, J. A. and Johnson, J. W., The dissipation of wave energy by bottom friction. Transactions of the American Geophysical Union, v. 30, 1949 : 67-73.
7. Stouppe, D. E., Ocean wave crest and ray refraction in shoaling water by computer. Master's Thesis, Department of Meteorology and Oceanography, United States Naval Postgraduate School, 1966.
8. Wilson, W. S., A method for calculating and plotting surface wave rays. U. S. Army Coastal Engineering Research Center, Tech. Mem. 17, 1966.
9. Wiegel, R. L., Oceanographic Engineering. Prentice Hall, 1964.

APPENDIX 1

Computer Program for Wave Refraction using Fortran 63

on the C.D.C. 1604 Computer

Subroutine Title: FRICT¹

Variables of Subroutine:

HHQ.....Height of wave at point X, Y after bottom friction
has been included.

RLO.....Deep water wave length.

RLQ.....Wave length at point X, Y.

CFF.....Friction factor between point n and n+1.

RCFF..... $(1 - K_f)$

TRCFF.....Total of $(1-K_f)$ terms to point n.

TCFF.....Total friction factor to point n.

Summary of Subroutine:

The subroutine calculates the value of K_f and wave height reduced by bottom friction (HHFR) for each point along wave ray.

¹ See Stoupe (1966) for discussion of remainder of program.

```

C      PROGRAM WAVREFR
C      REFRACTION IN SHOALING WATER BY LT. D. STOUPPE, OCTOBER 1966
C      WAVE REFRACTION PROGRAM FOR THE COMPUTATION OF CREST AND RAY
C      THE PROGRAM WAS MODIFIED BY LT. C. FARRELL, MAY 1967, TO
C      INCLUDE THE EFFECT OF FRICTION AND TIDE LEVEL. THE PROGRAM IS
C      WRITTEN IN FORTRAN 63 FOR THE CDC 1604 COMPUTER SYSTEM.
C      USERS MAY ENTER THE DESIRED NAMES FOR THE GRAPH TITLES IN THE
C      ITITLE STATEMENTS AS DESCRIBED IN THE WRITEUP ON THE DRAW
C      SUBROUTINE.
C      DIMENSION ITITLE(12),XXX(100),YYY(100),FX(100),FY(100)
C      COMMON/BLK1/X(100),Y(100),COREFR(1 ),HH0(100),B(3,100),FFK(100),
C      INOGO(100),NGO,AAA(100)
C      COMMON/BLK2/T,A,CXY,PAR,BAR,TIME,GRID,FK,MAX,NOR,MM,NN,DEPTH,HHA,
C      COREFA,NORA,L0,DIST
C      COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPYY
C      1,PDDPXY,PDDPCC,PDFC
C      COMMON/BLK4/FFKK(100),DLO,C(6),MIT,DEL X,DEL Y,FCF,TIDE,HINT,
C      1HHF,HHFR(100),LQQ,HHQ,DEPTH1
C      READ 74,MM,NN
C      74 FORMAT(2I10)
C      NOTE MM AND NN MUST BE RIGHT ADJUSTED
C      READ 1,((DEP(I,J),J=1,NN),I=1,MM)
C      1 FORMAT (14F5.0)
C      333 READ 2,XV,YV,FCF,TIDE,HINT,T,A1,NOR,TIME,DIST,GRID
C      2 FORMAT (2F7.0,F5.2,4F5.1,I5,F5.1,2F7.0)
C      PRINT 19
C      19 FORMAT (1H1,2X,2HXV,5X,2HYV,4X,3HFCF,1X,4HTIDE,1X,4HHINT,2X,
C      11HT,4X,2HA1,2X,3HNOR,2X,4HTIME,2X,4HDIST,3X,4HGRID)
C      PRINT 2,XV,YV,FCF,TIDE,HINT,T,A1,NOR,TIME,DIST,GRID
C      DO 516 I=1,MM $ DO 516 J=1,NN
C      IF(DEP(I,J))501,516,502
C      501 DEP(I,J)=DEP(I,J)*6.0-TIDE
C      GO TO 516
C      502 DEP(I,J)=DEP(I,J)*6.0+TIDE
C      516 CONTINUE
C      B1=1.0
C      0000000
C      0000010
C      0000020
C      0000030
C      0000040
C      0000050
C      0000060
C      0000070
C      000008
C      0000090
C      0000100
C      000011
C      0000120
C      000013
C      0000140
C      000015
C      0000160
C      000017
C      000018
C      000019
C      0000200
C      000021
C      000022
C      0000230
C      0000240
C      000025
C      0000260
C      0000270
C      0000280
C      000029
C      000030
C      000031
C      000032
C      000033
C      000034
C      000035

```

```

B2=1.0
MAX=1 $ A1=A1*.01745329 $ PAR=32.2*T/6.283185 $ BAR=6.283185/T
LQQ=1
NIP=4
IFG=TIDE $ IAQ=A1 $ ITQ=T
LABEL=4H
DO 18 M=1,12
18 ITITLE(M)=8H $ ITITLE(1)=8HFARRELL $ ITITLE(2)=8H WAVE RE
ITITLE(3)=8HFRACTION $ ITITLE(4)=8H PROGRAM
ITITLE(5)=8H MONTER
ITITLE(6)=8H EY BAY
ITITLE(7)=8HTIDE LVL
ITITLE(8)=IBCD(IFG,0,4,IEQ)
ITITLE(9)=8HANGLE =
ITITLE(10)=IBCD(IAQ,0,4,IEQ)
ITITLE(11)=8HPERIOD =
ITITLE(12)=IBCD(ITQ,0,4,IEQ)
B(1,1)=B1 $ B(2,1)=B2 $ XX=XV $ YY=YV $ NORA=1 $ A=A1
IF(T-10.)15,16,17
15 CXY= 30.0 $ GO TO 3
16 CXY= 50.0 $ GO TO 3
17 CXY=80.0 $ GO TO 3
5 B(1,NORA)=B1 $ B(2,NORA)=B2 $ A=A1
XV=XV-DIST*SINF(A) $ YV= YV+DIST*COSF(A)$XX=XV $ YY=YV $ GO TO 3
23 NORA=1
24 XX=X(NORA) $ YY=Y(NORA) $ A=AAA(NORA)
3 CALL RAYN(XX,YY,NOR)
CONTINUE $ NORA=NORA+1 $ IF(NORA-NOR)10,10,4
10 IF(MAX-1)5,5,24
4 IF(MAX-1)20,20,25
25 IF(NIP-4)21,26,26
20 CALL DRAW(NOR,X,Y,1,2,LABEL,ITITLE,10000.,10000.,0,0,2,2,9,9 ,1,
1EAST) $ GO TO 27
26 CALL DRAW(NOR,X,Y,2,2,LABEL,ITITLE,10000.,10000.,0,0,2,2,9,9 ,1,
1EAST)
27 CALL DRAW(NOR,X,Y,2,0,LABEL,ITITLE,10000.,10000.,0,0,2,2,9,9 ,1,
1EAST)

```

```

1 LAST)
  NIP=1
21 NIP=NIP+1 $ MAX=MAX+1 $ MIN=MAX-1
33 DO 32 M=1,NOR $ FX(M)=X(M)/3. $ FY(M)=Y(M)/3.
32 CONTINUE
34 PRINT 28,MIN
28 FORMAT(/17HNUMBER OF CREST = I4/)
  PRINT 6
6 FORMAT(/4X,1HX,9X,1HY,6X,6HCOREFA,3X,3HHH0,5X,4HHHFR,5X,5HDEPTH,
11X,3HNGO,6X,1HX,7X,2HY,6X,6HCOREFA,3X,3HHH0,5X,4HHHFR,5X,5HDEPTH,
21X,3HNGO)
  DO 7 J=1,NOR,2
  PRINT 8,FX(J),FY(J),COREFR(J),HH0(J),HHFR(J),DEPTH1(J),NORO(J),
1FX(J+1),FY(J+1),COREFR(J+1),HH0(J+1),HHFR(J+1),DEPTH1(J+1),
2NORO(J+1)
8 FORMAT(2(2F9.1,3F8.4,F9.1,I4)/)
7 CONTINUE
  DO 9 I=1,NOR $ DO 9 J=2,3
9 B(J,1,I)=B(J,I) $ NNGO=0 $ DO11 K=1,NOR
  IF(NORO(K)-1)12,12,11
12 NNGO=NNGO+1
11 CONTINUE $ IF(NNGO-NOR) 13,14,14
13 GO TO 23
14 CONTINUE
  M=1 $ DO31I=1,MM $ DO31J=1,NN $ IF(DEP(I,J))31,30,31
30 XXX(M)=(I-1)*GRID $ YYY(M)=(J-1)*GRID $ M=M+1 $ N=M-1
31 CONTINUE
  CALL DRAW(N,XXX,YYY,3,0,LABEL,ITITLE,10000.,10000.,0,0,2,2,9,9 ,
11,1,1,1)
  DO616 I=1,MM $ DO616J=1,NN
  IF(DEP(I,J))601,616,602
601 DEP(I,J)=(DEP(I,J)+TIDE)/6.0
  GO TO 616
602 DEP(I,J)=(DEP(I,J)-TIDE)/6.0
616 CONTINUE
  GO TO 333

```

```

0000072
0000073
0000074
00000750
0000076
0000077
0000078
0000079
00000800
00000810
0000082
0000083
00000840
00000850
0000086
0000087
0000088
0000089
00000900
0000091
0000092
0000093
0000094
0000095
00000960
00000970
0000098
00000990
0000100
0000101
0000102
0000103
0000104
0000105
0000106
0000107

```



```

END
SUBROUTINE RAYN(XX,YY,NOR)
COMMON/BLK1/X(100),Y(100),COREFR(1),HHO(100),B(3,100),FFK(100),
1NNGO(100),NGO,AAA(100)
COMMON/BLK2/T,A,CXY,PAR,BAR,TIME,GRID,FK,MAX,ABC,MM,NN,DEPTH,HHH,
1COREFA,NORA,L0,DIST
COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPYY
1,PDDPXY,PDDPCC,PDPC
COMMON/BLK4/FFKK(100),DLO,C(6),MIT,DEL X,DEL Y,FCF,TIDE,HINT,
1HHF,HHFR(100),LQQ,HHQ,DEPTH1
IF(MAX-1)110,110,111
110 NGO=2 $ GO TO 108
111 NGO=NGO(NORA) $ GO TO (104,108)NGO
108 CALL DEPTFUN(XX,YY)
GO TO (104,102)NGO
104 NGO=1
GOREFA=0.0
B(3,NORA)=0.0
FK= .0
HHA=0.0
HHF=0.0
GO TO 103
102 IF(MAX-1)105,105,107
105 CALL KFUNCT(A,FK) $ GO TO 106
107 FK=FFK(NORA)
106 CALL MOVE(XX,YY) $ GO TO(104,109)NGO
109 CALL BETA(XX,YY)
103 FFK(NORA)=FK $ COREFR(NORA)=COREFA $ HHO(NORA)
1=HHA $ NNGO(NORA)=NGO $ X(NORA)=XX $ Y(NORA)=YY $ AAA(NORA)=A
DEPTH1(NORA)=DEPTH
HHFR(NORA)=HHF
RETURN
END
SUBROUTINE DEPTFUN(XX,YY)
DIMENSION D(6,6),E(6), O(100),P(100)
COMMON/BLK1/X(100),Y(100),COREFR(1),HHO(100),B(3,100),FFK(100),

```

```

1 INOGO(100),NGO,AAA(100)
COMMON/BLK2/T,A,CXY,PAR,BAR,TIME,GRID,FK,MAX,NOR,MM,NN,DEPTH,HHA,
1 COREFA,NORA,L0,DIST
COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPPY
1,PDDPPXY,PDDPCC,PDPC
COMMON/BLK4/FFKK(100),DLO,C(6),MIT,DEL X,DEL Y,FCF,TIDE,HINT,
1 HHF,HHFR(100),LQQ,HHQ,DEPTH1
XR=XX/GRID $ K=XR+1.5 $ YR=YY/GRID $ L=YR+1.5
IF((XX-1.0)*((MM-1)-K))62,7,7
7 IF((YY-1.0)*((NN-1)-L))62,6,6
6 D09J=1,6 $ D09I=1,6
9 D(I,J)=0.0 $ D08 I=1,6
8 E(I)=0.0
M=L 1 $ MA=L+1 $ N=K-1 $ NA=K+1
D01 J=M,MA $ D010 I=N,NA $ O(I)=(I-1)*GRID $ P(J)=(J-1)*GRID
D(1,1)=9.0$D(2,1)=D(2,1)+O(I)$D(3,1)=D(3,1)+P(J)$D(4,1)=D(4,1)+O(I)
1)*P(J)$D(5,1)=D(5,1)+O(I)**2$D(6,1)=D(6,1)+P(J)**2$E(1)=E(1)+DEP
2(I,J)$D(1,2)=D(2,1)$D(2,2)=D(5,1)$D(3,2)=D(4,1)$D(4,2)=D(4,2)+O(I)
3)**2*P(J)$D(5,2)=D(5,2)+O(I)**3$D(6,2)=D(6,2)+O(I)*P(J)**2$E(2)=
4E(2)+O(I)*DEP(I,J)$D(1,3)=D(3,1)$D(2,3)=D(4,1)$D(3,3)=D(6,1)$D(4,
53)=D(4,3)+O(I)*P(J)**2$D(5,3)=D(4,2)$D(6,3)=D(6,3)+P(J)**3$E(3)=
6E(3)+P(J)*DEP(I,J)$D(1,4)=D(4,1)$D(2,4)=D(4,2)$D(3,4)=D(6,2)$D(4,
74)=D(4,4)+O(I)**2*P(J)**2$D(5,4)=D(5,4)+O(I)**3*P(J)$D(6,4)=D(6,4)
8)+O(I)*P(J)**3$E(4)=E(4)+O(I)*P(J)*DEP(I,J)$D(1,5)=D(5,1)$D(2,5)=
9D(5,2)$D(3,5)=D(4,2)$D(4,5)=D(5,4)$D(5,5)=D(5,5)+O(I)**4$D(6,5)=
1D(4,4)$E(5)=E(5)+O(I)**2*DEP(I,J)$D(1,6)=D(6,1)$D(2,6)=D(6,2)$D(3
2,6)=D(6,3)$D(4,6)=D(6,4)$D(5,6)=D(4,4)$D(6,6)=D(6,6)+P(J)**4$E(6)
3=E(6)+P(J)**2*DEP(I,J)
10 CONTINUE
NPM=7 $ DO 34M=1,6 $ KP=0 $ Z=0.0 $ D012N=M,6 $ IF(Z-ABSF(D(N,M)
1),11,12,12
11 Z=ABSF(D(N,M)) $ KP=N
12 CONTINUE $ IF(M-KP)13,20,20
13 D014J=M,NPM $Z=D(M,J) $ D(M,J)=D(KP,J)
14 D(KP,J)=Z
20 IF(ABSF(D(M,M))-0.00001)50,50,30
0000144
00001450
0000146
00001470
0000148
00001490
0000150
00001510
0000152
0000153
0000154
0000155
0000156
0000157
00001580
00001590
00001600
00001610
00001620
00001630
00001640
00001650
00001660
00001670
00001680
00001690
00001700
0000171
0000172
00001730
0000174
0000175
0000176
00001770
0000178
0000179

```



```

30 IF(M-6)31,40,40
31 LPI=M+1 $ DO34N=LPI,6 $ IF(D(N,M))32,34,32
32 RATIO=D(N,M)/D(M,M)$ DO33J=LPI,NPM
33 D(N,J)=D(N,J)-RATIO*D(M,J)
34 CONTINUE
40 DO43I=1,6 $ II=7-I $ JPN=7 $ S=0.0 $ IF(II-6)41,43,
143
41 IIP1=II+1 $ DO 42N=IIP1,6
42 S=S D(II,N)*C(N)
43 C(II) =(D(II,JPN)-S)/D(II,II) $ KER=1 $ GO TO 51
50 KER=2
PRINT 54,XX,YY,KER
54 FORMAT(/3X,5HXX = 1PE20.8,3X,5HYY = 1PE20.8,4X,6HKER = 12,
117H MATRIX SINGULAR/)
51 GO TO (52,53)KER
53 RETURN
52 CONTINUE
DEPTH=C(1)+C(2)*XX+C(3)*YY+C(4)*XX*YY+C(5)*XX**2+C(6)*YY**2
IF(DEPTH)62,62,65
65 AL0=PAR*T $ DL0=DEPTH/AL0 $ IF(DL0 .5)63,63,66
66 CXY=PAR $ L0=1 $ NGO=2 $ FK=0. $ GO TO 67
63 DO6 M=1,50 $ CXX=PAR*TANHFBAR*DEPTH/CXY)
IF(ABSF(CXX-CXY)-0.01)61,61,60
60 CXY=(CXX+CXY)*.5
61 CONTINUE $ NGO=2 $ L0=2
67 PDPX=C(2)+C(4)*YY+2*C(5)*XX
PDPY=C(3)+C(4)*XX+2*C(6)*YY
PDDPXY=C(4) $ PDDPXX=2*C(5) $ PDDPPY=2*C(6)
GO TO 64
62 NGO=1
GO TO 81
64 CONTINUE
81 RETURN
END
SUBROUTINE KFUNCT (A,FK)
COMMON/BLK1/X(100),Y(100),COREFR(1 ),HH0(100),B(3,100),FFK(100),
0000180
00001810
0000182
0000183
0000184
00001850
186
0000187
0000188
00001890
0000190
0000191
00001920
0000193
0000194
0000195
0000196
00001970
0000198
00001990
00002000
00002010
0000202
0000203
0000204
0000205
0000206
00002070
0000208
0000209
0000210
0000211
0000212
213
0000214
00002150

```

```

1 NGO(100),NGO,AAA(100)
COMMON/BLK2/T,UU,CXY,PAR,BAR,TIME,GRID,VV,MAX,NOR,MM,NN,DEPTH,HHA
1 COREFA,NORA,LO,DIST
COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPPY
1 PDDPXY,PDDPCC,PDPC
3 GO TO (5,6)LO
6 R1=CXY/32.2 $ R2=R1**3*BAR**2 $ R3=R1**5*BAR**4 $ R4=R1**7*BAR**6
PDPC=2.*R1+4.*R2/3.+6.*R3/5.+8.*R4/7.
PDDPCC=(2.*R1+4.*R2+6.*R3+8.*R4)/CXY
PCPX=PDPX/PDPC $ PCPY=PDPY/PDPC
FK=(PCPX*SINF(A)-PCPY*COSF(A))/CXY $ GO TO 4
5 FK= .
4 RETURN
END
SUBROUTINE MOVE(X,Y)
COMMON/BLK1/U(100),V(100),COREFR(1 ),HHO(100),B(3,100),FFK(100),
1 NGO(100),NGO,AAA(100)
COMMON/BLK2/T,A,CXY,PAR,BAR,TIME,GRID,FK,MAX,NOR,MM,NN,DEPTH,HHA,
1 COREFA,NORA,LO,DIST
COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPPY
1 PDDPXY,PDDPCC,PDPC
COMMON/BLK4/FFKK(100),DLO,C(6),MIT,DEL X,DEL Y,FCF,TIDE,HINT,
1 HHF,HHFR(100),LQQ,HHG,DEPTH1
FKBAR=FFKK(NORA)
IF(MAX-1)1,1,4
1 FKBAR=FK
4 MIT=1
DEL D=TIME*CXY
GO TO (22,21)LO
22 XX=X+DELD*COSF(A) $ YY=Y+DELD*SINF(A) $ AA=A $ FKK=0. $ FKBAR=0.
GO TO 6
21 DO 20IT=1,30
19 DEL A=FKBAR*DEL D $ AA=A+DEL A $ ABAR=A+.5*DEL A $ DEL X=DEL D*
1 COSF(ABAR) $ DEL Y=DEL D*SINF(ABAR) $ XX=X+DEL X $ YY=Y+DEL Y
GO TO (101,6)MIT
101 CALL DEPTFUN(XX,YY) $ GO TO(38,10)NGO

```

```

10 CALL KFUNCT(AA,FKK) $ FKBAR=.5*(FK FKK)
IF(IT-13)5,37,9
37 FKKPP=FKBAR
5 IF(MAX-1)7,7,9
7 IF(IT-1)20,20,9
9 IF(ABSF(FKKP-FKBAR)-.00001)6,6,20
20 FKKP=FKBAR
24 IF(ABSF(FKKPP-FKBAR)-.00001)18,18,17
17 MIT=3 $NGO=1
GO TO 38
18 FKBAR=.5*(FKBAR+FKKP) $ MIT=2 $ GO TO 19
6 NGO=2 $ GO TO 8
8 X=XX $ Y=YY $ A=AA $ FK=FKK
38 CONTINUE
FFKK(NORA)=FKBAR
RETURN
END
SUBROUTINE BETA(XX,YY)
COMMON/BLK1/X(100),Y(100),COREFR(1 ),HHO(100),B(3,100),FFK(100),
1NGO(100),NGO,AAA(100)
COMMON/BLK2/T,A,CXY,PAR,BAR,TIME,GRID,FK,MAX,NOR,MM,NN,DEPTH,HHA,
1COREFA,NORA,L0,DIST
COMMON/BLK3/DEP(100,100),PDPX,PDPY,PCPX,PCPY,PDDPXX,PDDPPY
1,PDDPPY,PDDPCC,PDPC
COMMON/BLK4/FFKK(100),DLO,C(6),MIT,DEL X,DEL Y,FCF,TIDE,HINT,
1HHF,HHFR(100),LQQ,HHQ,DEPTH1
GO TO (5,6)L0
5 COREFA=1. $ HHA=1. $ B(3,NORA)=B(2,NORA) $ COREFB=1. $ HHB=1.
HHF=1.0
GO TO 7
6 PCCPXX=PDDPXX/(PDPC+PDDPCC)
PCCPY=PDDPPY/(PDPC+PDDPCC)
PCCPX=PDDPXY/(PDPC+PDDPCC)
P=( COSF(A)*PCPX-SINF(A)*PCPY)/CXY $ Q=(SINF(A)**2*PCCPXX-2.*
1SINF(A)*COSF(A)*PCCPY+COSF(A)**2*PCCPY)/CXY
DD=SQRTF((DEL X)**2+(DEL Y)**2)

```

```

B(3,NORA)=(B(1,NORA)*(P*DD-2.)+B(2,NORA)*(4.-2.*DD**2*Q))
1/(2.+P*DD)
COREFA=1./SQRTF(ABSF(B(2,NORA)))
CC0=CXY/PAR $ HSHOL=3.2519-12.8150*CC0+28.8112*CC0**2-29.9257*CC0
1**3 11.6815*CC0**4 $ HHA=COREFA * HSHOL
CALL FRIC (HHA,CXY,TIME,DEPTH,LQQ,PAR,T,HHF,NORA,NOR,
1FCF,HINT,HSHOL)
7 RETURN
END
SUBROUTINE FRIC(HHA,CXY,TIME,DEPTH,LQQ,PAR,T,HHF,NORA,NOR,
1FCF,HINT,HSHOL)
296
00002970
0000298
0000299
0000300
0000301
0000302
0000303
0000304
0000305
0000306
0000307
0000308
00003090
0000310
0000311
0000312
0000313
0000314
0000315
00003160
0000317
0000318
0000319
0000320
0000321
0000322
323
DIMENSION TCFF(100),TRCFF(100)
1 CC0=CXY/PAR
DEL D=TIME*CXY
IF(LQQ-1)715,701,715
701 DO 8 I=1,NOR
TCFF(I)=1.0
TCFF(I)=1.0
TRCFF(I)=0.0
8 CONTINUE
TFP=T**4
THET1=64.0*(3.141592**3)/(3.0*(32.2**2))
715 HHQ=HHA*HINT*TCFF(NORA)
RLO=PAR*T
RLO=RLO*CC0
APR=FCF*HHQ/TFP
THET2=SINH(6.28315*DEPTH/RLO)
THETA=THET1*((HSHOL/THET2)**3)
CFF=1.0/((APR*THETA*DEL D/HSHOL)+1.)
RCFF=1.-CFF
TRCFF(NORA)=TRCFF(NORA)+RCFF
TCFF(NORA)=1.-TRCFF(NORA)
HHF=HHQ/HINT
LQQ=5
RETURN
END

```


EXP	IDENT	SINHF	SINHF001
EXP1	SYSTEM	SINHF	SINHF002
EXP2	ENTRY	SINHF	SINHF003
EXP3	DEC	709.089	SINHF004
EXP4	DEC	-709.78	SINHF005
EXP5	OCT	2000542710277575	SINHF006
EXP6	OCT	204440000002000	SINHF007
EXP7	OCT	2002561250731225	SINHF008
EXP8	OCT	1773433546344024	SINHF009
ONE	OCT	2003704560677011	SINHF01
HALF	OCT	2007535620560566	SINHF011
SINHF	OCT	-0	SINHF012
	DEC	1.0	SINHF013
	DEC	0.5	SINHF014
	SLJ	**	SINHF015
	SIU	1 SINH3	SINHF016
	LIU	1 SINHF	SINHF017
	LDA	1 0	SINHF018
	ARS	24	SINHF019
	SAU	SINH1	SINHF020
	INI	1	SINHF021
	SIL	1 SINH3	SINHF022
SINH1	LDA	**	SINHF023
	AJP	SINH3	SINHF024
	THS	EXP	SINHF025
	SLJ	ERROR1	SINHF026
	THS	EXP1	SINHF027
	SLJ	*+2	SINHF028
	SLJ	ERROR1	SINHF029
	FDV	EXP2	SINHF03
+	STA	=STEMP	SINHF031
	FSB	EXP3	SINHF032
	SAL	SINH2	SINHF033
	FAD	EXP3	SINHF034
	FSB	TEMP	SINHF035
	STA	TEMP	SINHF036
		STORE ARGUMENT	
		STORE RETURN ADDRESS	
		EXIT IF ZERO	
		CHECK MAXIMUM X	
		CHECK MINIMUM X	

FMU	TEMP	SINH2	SINH037
STA	=STEMP1		SINH038
FAD	EXP7		SINH039
STA	=STEMP2		SINH04
LDA	EXP6		SINH041
FDV	TEMP2		SINH042
FAD	EXP5		SINH043
FMU	TEMP1		SINH044
FAD	EXP4		SINH045
STA	TEMP2		SINH046
FAD	TEMP		SINH047
STA	TEMP1		SINH048
LDA	TEMP2		SINH049
FSB	TEMP		SINH05
FDV	TEMP1		SINH051
LRS	36		SINH052
INA	**		SINH053
AJP	2 *+1		SINH054
INA	-1		SINH055
INA	2000B		SINH056
LLS	36		SINH057
AJP	3 ERROR1		SINH058
STA	TEMP		SINH059
LDA	ONE		SINH06
FDV	TEMP		SINH061
SCM	EXP8		SINH062
FAD	TEMP		SINH063
FMU	HALF		SINH064
SLJ	SINH3		SINH065
ENI	1 **	SINH3	SINH066
SLJ	**		SINH067
LDQ	ERROR2		SINH068
CALL	Q8QIBJOB		SINH069
BCD	1SINH OUT		SINH07
CALL	Q8QEXITS		SINH071
51	6 14567B		SINH072
ERROR2			
ERROR1			
SINH3			


```

65      SINHF
END
FUNCTION IBCD(NX,JT,NJ,IER)
DIMENSION NN(8),NNT(8)
NT=XABSF(NX)
IER=0 $ NEG=0 $ BLANK=20B
NP=XMODF(NJ,8)
IF(JT.EQ.0) 51,52
52 IF(JT.EQ.1) 51,53
53 IER=2 $ IBCD=20202020202020B $ GO TO 60
C CHECK IF INPUT IS MORE THAN EIGHT PLACES
51 IF(NX) 5,6,7
7 NEG=1
IF(NX.GT.999999999) 10,17
10 NT=999999999
IER=1
60 TO 17
5 IF(NX.LT.-999999999) 12,17
12 NT= 99999999
IER=-1
17 FTEN=NT
DO 1 I=1,8
J=9 I
NN(J)=MODF(FTEN,10.)
1 FTEN=INTF(FTEN/10.)
60 TO 25
C IF INPUT IS ZERO SET ALL BLANK EXCEPT NN(8)=0
6 DO 40 I=1,7
40 NN(I)=BLANK
NN(8)=12B
JBL=7
60 TO 21
25 DO 3 I=1,8
IF(NN(I).EQ.0) 4,8
4 NN(I)=BLANK
3 CONTINUE

```

SINHF073
SINHF074

00000
00001
00002
00003
00004
00005
00006
000070
000080
00009
00010
00011
00012
00013
00014
00015
00016
00017
00018
00019
00020
00021
00022
00023
000240
00025
00026
00027
00028
00029
00030
00031
00032
00033

```

8 JBL=I-1
  DO 41 KK=1,8
    IF(NN(KK).EQ.0) 42,41
42 NN(KK)=12B
41 CONTINUE
    IF(NEG.EQ.0) 20,21
20 NN(JBL)=40B $ JBL=JBL-1
21 IF(NP-JBL)26,26,27
27 NP=
26 IF(JT.EQ.0) 30,31
30 KJ=NP $ GO TO 32
31 KJ=JBL-NP
32 NK=KJ+1
  DO 33 K=NK,8
33 NNT(K-KJ)=NN(K)
  DO 34 K=1,KJ
34 NNT(K+8-KJ)=NN(K)
50 ENCODE(8,50,IBCD) (NNT(I),I=1,8)
60 FORMAT(8R1)
END

```

```

00034
00035
00036
00037
00038
00039
00040
00041
42
00043
00044
00045
00046
00047
00048
00049
00050
00051
00052
53

```

APPENDIX 2

Sample Computer Input and Output

Sample Input

52

56

```

440. 460. 515. 505. 510. 470. 425. 355. 300. 330. 370. 360.
340. 345. 350. 365. 375. 390. 455. 560. 700. 850. 950. 865.
550. 490. 470. 460. 415. 380. 335. 400. 460. 520. 560. 595.
510. 460. 400. 315. 275. 300. 220. 140. 80. 55. 53. 51.
360. 405. 450. 435. 445. 380. 330. 270. 235. 250. 280. 280.
290. 297. 300. 305. 315. 360. 420. 490. 655. 810. 930. 870.
540. 500. 515. 515. 480. 445. 440. 500. 540. 593. 630. 630.
610. 560. 515. 400. 315. 275. 234. 190. 110. 63. 53. 50.
295. 370. 370. 325. 325. 307. 260. 190. 170. 175. 190. 190.
240. 250. 250. 265. 275. 305. 405. 470. 570. 750. 900. 885.
560. 540. 550. 560. 550. 540. 550. 605. 620. 640. 610. 570.
540. 590. 570. 430. 300. 310. 280. 240. 170. 70. 55. 50.
240. 250. 235. 195. 225. 200. 190. 160. 130. 140. 160. 170.
190. 195. 210. 230. 250. 280. 350. 427. 490. 670. 820. 860.
610. 590. 590. 615. 600. 610. 620. 660. 650. 620. 560. 505.
480. 520. 560. 515. 405. 370. 320. 260. 190. 80. 60. 49.
150. 195. 200. 110. 125. 120. 115. 95. 80. 98. 105. 110.
162. 170. 180. 205. 210. 210. 290. 380. 455. 580. 740. 785.
660. 650. 640. 660. 660. 670. 690. 685. 650. 585. 510. 480.
450. 490. 550. 525. 450. 380. 325. 270. 215. 120. 65. 50.
80. 80. 90. 75. 73. 70. 72. 70. 70. 70. 72. 80.
110. 120. 140. 160. 175. 195. 240. 290. 390. 475. 610. 670.
760. 720. 715. 725. 730. 710. 680. 655. 620. 540. 480. 445.
440. 410. 550. 490. 415. 370. 325. 285. 235. 170. 85. 65.
61. 60. 60. 58. 60. 60. 61. 63. 60. 60. 65. 65.
80. 85. 100. 120. 130. 120. 160. 230. 280. 380. 460. 540.
770. 750. 735. 715. 665. 635. 620. 610. 570. 485. 440. 415.
425. 490. 550. 500. 445. 375. 315. 295. 245. 190. 110. 80.
47. 47. 48. 49. 52. 54. 53. 54. 56. 59. 60. 60.
63. 65. 70. 77. 82. 85. 110. 150. 185. 250. 340. 395.
560. 610. 590. 600. 570. 540. 525. 520. 500. 460. 410. 380.
420. 510. 515. 500. 465. 410. 283. 265. 235. 210. 145. 105.

```

```

4500. 2      . .01 0.    5.0 18.0 10.0    10 30.0 1500.0 1500.0
4500. 2      . .01 6.    5.0 18.0 10.0    10 30.0 1500.0 1500.0

```

SAMPLE COMPUTER OUTPUT

XV YV FCF TIDE HINT T AL NOR TIME DIST GRID
4500 20000 .1 5.0 18.0 10.0 19 33.0 1500 1500

NUMBER OF CREST = 1

X	Y	COREFA	HHO	HHFR	DEPTH	NGO	Y'	X	HHFR	HH	HHFR	DEPTH	NGO
2498.4	6826.0	1.0000	1.0000	1.0000	1112.9	2	7319.3	2321.6	1.0000	1.0000	1.0000	1229.3	2
2234.8	7811.7	1.0000	1.0000	1.0000	1288.8	2	83.4.1	2148.0	1.0000	1.0000	1.0000	1413.1	2
2061.2	8796.5	1.0000	1.0000	1.0000	1537.5	2	9288.9	1974.3	1.0000	1.0000	1.0000	1659.9	2
1887.5	9781.3	1.0000	1.0000	1.0000	1984.2	2	10273.7	1800.7	1.0000	1.0000	1.0000	2514.5	2
1713.9	10766.1	1.0000	1.0000	1.0000	3051.2	2	11253.5	1627.0	1.0000	1.0000	1.0000	3891.6	2

NUMBER OF CREST = 2

X	Y	COREFA	HHO	HHFR	DEPTH	NGO	Y'	X	HHFR	HH	HHFR	DEPTH	NGO
3309.2	6972.2	1.0000	.9195	.9195	405.2	2	7478.7	3225.7	1.0000	.9316	.9316	443.0	2
3143.2	7971.8	1.0000	1.0000	1.0000	943.6	2	8464.2	3056.4	1.0000	1.0000	1.0000	1096.7	2
2969.6	8956.6	1.0000	1.0000	1.0000	1181.9	2	9449.1	2882.8	1.0000	1.0000	1.0000	1258.6	2
2796.0	9941.5	1.0000	1.0000	1.0000	1637.4	2	10433.9	2709.1	1.0000	1.0000	1.0000	2165.4	2
2622.3	10926.3	1.0000	1.0000	1.0000	2594.4	2	11418.7	2535.5	1.0000	1.0000	1.0000	3411.9	2

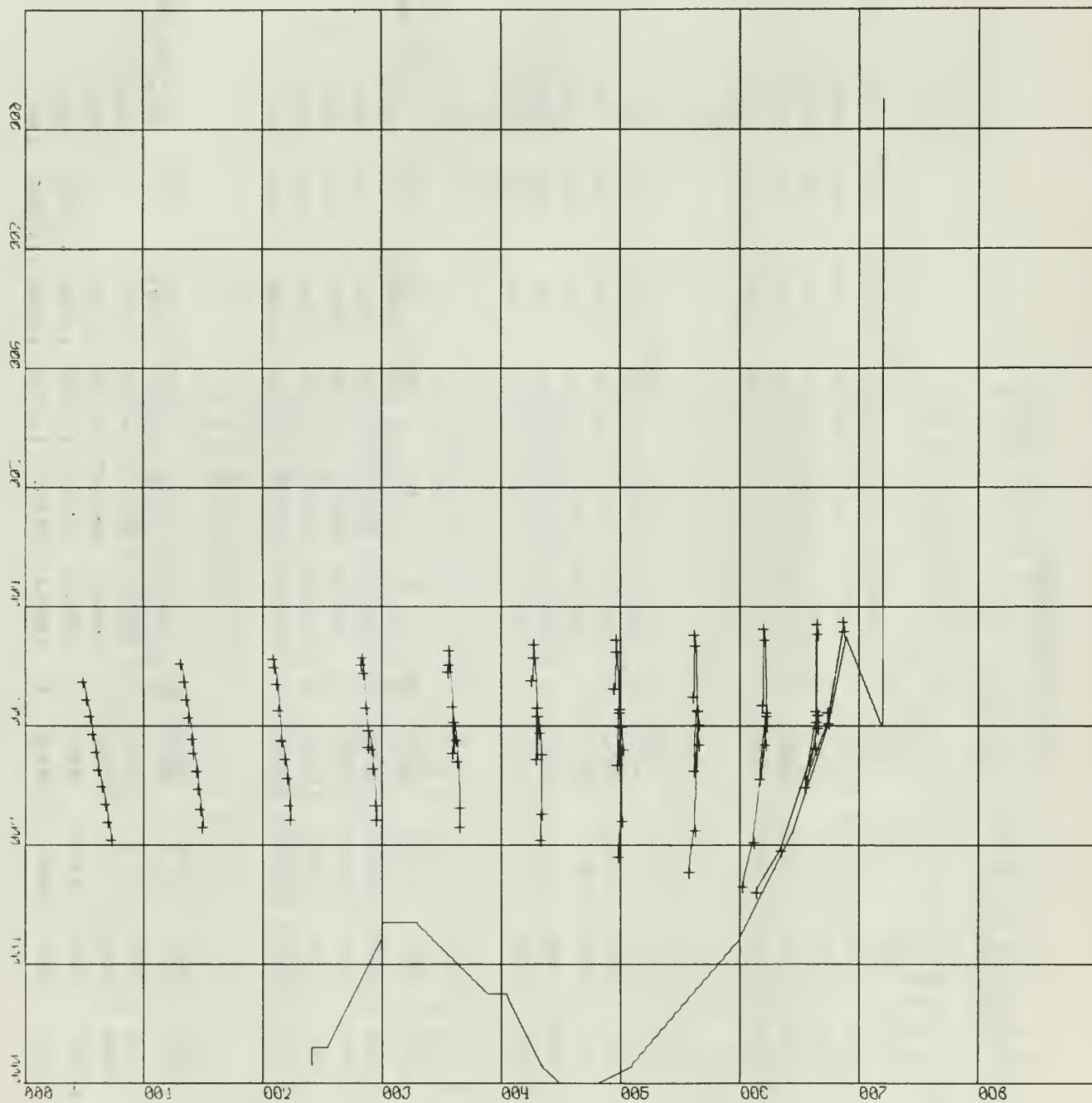
NUMBER OF CREST = 3

X	Y	COREFA	HHO	HHFR	DEPTH	NGO	Y'	X	HHFR	HH	HHFR	DEPTH	NGO
4158.6	7085.7	1.0156	.9203	.9061	359.4	2	76.4.8	4087.5	1.0000	.9846	.9846	368.1	2
4027.3	8117.6	1.0000	.9129	.9129	383.7	2	8622.6	3954.7	1.0000	.9214	.9214	411.3	2
3872.6	9115.9	1.0000	.9293	.9293	435.9	2	9577.9	3792.6	1.0000	.9396	.9396	468.5	2
3704.4	10101.6	1.0000	1.0000	1.0000	1117.0	2	10594.0	3617.6	1.0000	1.0000	1.0000	1578.3	2
3530.8	11086.4	1.0000	1.0000	1.0000	2050.3	2	11578.9	3443.9	1.0000	1.0000	1.0000	2752.1	2

NUMBER OF CREST = 4

X	Y	COREFA	HHO	HHFR	DEPTH	NGO	Y'	X	HHFR	HH	HHFR	DEPTH	NGO
4988.6	7180.2	1.0415	.9413	.9179	350.2	2	7678.5	4924.0	1.2019	1.0885	.9093	357.4	2
4866.2	8237.5	1.0222	.9273	.9012	363.2	2	8762.2	4807.7	1.0003	.9093	.9093	370.0	2
4729.3	9258.8	.9928	.9012	.9170	365.6	2	9640.9	4669.1	1.1038	1.0038	.9093	371.4	2
4596.8	10242.5	1.0000	.9170	.9170	397.4	2	10754.2	4526.0	1.0000	1.0000	1.0000	854.8	2
4439.2	11246.6	1.0000	1.0000	1.0000	1124.6	2	11739.0	4352.4	1.0000	1.0000	1.0000	1685.6	2

SAMPLE COMPUTER OUTPUT



X-SCALE = 1.00E+04 UNITS/INCH.

Y-SCALE = 1.00E+04 UNITS/INCH.

FARRELL WAVE REFRACTION PROGRAM MONTEREY BAY
TIDE LVL 0 ANGLE = 0 PERIOD = 18

APPENDIX 3

SUMMARY OF EQUATIONS

Wave Speed (C)

$$C = \frac{g T}{2\pi} \tanh \left(\frac{2\pi d}{T C} \right) .$$

Ray Curvature (FK)

$$FK = \frac{1}{c} \left[\sin A \frac{\partial c}{\partial H} - \cos A \frac{\partial c}{\partial y} \right] .$$

Coefficient of Refraction (K_r)

The value of ray separation (β) is calculated by solving the second order, non-linear differential equation:

$$\frac{D^2 \beta}{D S^2} + P \frac{D \beta}{D S} + q \beta = 0$$

where

$$P = -\cos A \frac{1}{c} \frac{\partial c}{\partial H} - \sin A \frac{1}{c} \frac{\partial c}{\partial y}$$

$$q = \sin^2 A \frac{1}{c} \frac{\partial^2 c}{\partial H^2} - 2 \sin A \cos A \frac{1}{c} \frac{\partial^2 c}{\partial H \partial y} + \cos^2 A \frac{1}{c} \frac{\partial^2 c}{\partial y^2} .$$

The above equation is solved by the finite difference method. This results in an equation for the Beta value at the $n+1$ point in terms of the Beta values at the two previous points. The equation to be solved is then:

$$\beta_3 = \frac{(PD - 2)\beta_1 + (4 - 2qD^2)\beta_2}{2 + PD} ;$$

where

D is the incremented distance

p, q are as defined above

β_1, β_2 are the Beta values of the two previous points. The

The coefficient of refraction is calculated by the relation:

$$K_r = \sqrt{1/\beta}$$

Direct Shoaling Coefficient (K_s):

$$H_s = 3.2519 - 12.8150 \left(\frac{c}{c_0} \right) + 28.8112 \left(\frac{c}{c_0} \right)^2 - 29.9257 \left(\frac{c}{c_0} \right)^3 + 11.6815 \left(\frac{c}{c_0} \right)^4.$$

Wave Height Reduction Factor Due to Bottom Friction (K_f):

$$K_f = \frac{1}{\frac{A' \phi_f}{K_s} \Delta T + 1},$$

where

$$A' = \frac{f H_s}{T^4}$$

$$\phi_f = \frac{64 \pi^3}{3 g^2} \left(\frac{K_s}{\sinh \frac{2 \pi d}{L}} \right)^3.$$

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2. Library Naval Postgraduate School Monterey, California 93940	2
3. Professor Glenn H. Jung Department of Meteorology and Oceanography Naval Postgraduate School Monterey, California 93940	3
4. LT Charles A. Farrell Department of Meteorology and Oceanography Naval Postgraduate School Monterey, California 93940	3
5. Department of Meteorology and Oceanography Naval Postgraduate School Monterey, California 93940	3
6. Office of the Naval Weather Service Naval Station (Washington Navy Yard Annex) Washington, D. C. 20390	1
7. Officer in Charge Naval Weather Research Facility Naval Air Station, Building R-48 Norfolk, Virginia 23511	1
8. Commanding Officer U. S. Fleet Weather Central Box 12, COMNAVMARIANAS FPO San Francisco, California 96601	1
9. Commanding Officer U. S. Fleet Weather Central Box 10 FPO San Francisco, California 96610	1
10. Commanding Officer U. S. Fleet Weather Central FPO New York, New York 09540	1
11. Officer in Charge Fleet Weather Facility Naval Air Station San Diego, California 92135	1

	No. Copies
12. Officer in Charge Fleet Numerical Weather Facility Naval Postgraduate School Monterey, California 93940	1
13. Director, Naval Research Laboratory Attn: Tech. Services Info. Officer Washington, D. C. 20390	1
14. Superintendent Naval Academy Annapolis, Maryland 21402	1
15. Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
16. Naval Oceanographic Office Attn: Library Washington, D. C. 20390	1
17. Director, Coast & Geodetic Survey Department of Commerce Attn: Office of Oceanography Washington, D. C. 20235	1
18. Office of Naval Research Department of the Navy Washington, D. C. 20360	
Attn: Special Projects (Code 418)	1
Attn: Geophysics Branch (Code 416)	1
Attn: Director, Surface and Amphibious Programs (Code 463)	1
Attn: Senior Marine and Amphibious Warfare Officer (Code 407M)	1
19. Mission Bay Research Foundation 7730 Herschel Avenue La Jolla, California 92038	1
20. LT David E. Stoupe, USN USS INDEPENDENCE (CVA-62) FPO, New York, New York 09501	1

	No. Copies
21. LCDR Gale M. Griswold Fleet Numerical Weather Facility Naval Postgraduate School Monterey, California 93940	3
22. Professor J. A. Putnam University of California Berkeley, California	1
23. Professor C. L. Bretschneider Chairman of Ocean Engineering University of Hawaii Honolulu, Hawaii 96822	1
24. Coastal Engineering Research Center Corps of Engineers, U. S. Army 5201 Little Falls Road, N. W. Washington, D. C. 20016	1
25. Chairman Department of Meteorology and Oceanography New York University University Heights, Bronx New York, New York	1
26. Chairman Department of Meteorology and Oceanography University of Hawaii Honolulu, Hawaii	1
27. Chairman Department of Oceanography Oregon State University Corvallis, Oregon 97331	1
28. Chairman Department of Oceanography Texas A&M University College Station, Texas 77843	1
29. Director, Biological Laboratory Bureau of Commercial Fisheries U. S. Fish and Wildlife Service 450-B Jordan Hall Stanford, California	1
30. Geophysical Institute Tokyo University Bunkyo-ku Tokyo, Japan	1

- | | | |
|-----|--|---|
| 31. | Director
Pacific Oceanographic Group
Nanaimo, British Columbia
Canada | 1 |
| 32. | Ocean Research Institute
University of Tokyo
Tokyo, Japan | 1 |
| 33. | Secretary
Canadian Committee on Oceanography
Ottawa, Canada | 1 |
| 34. | Chairman
Department of Oceanography
University of Rhode Island
Kingston, Rhode Island | 1 |

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE TIDE-LEVEL AND BOTTOM-FRICTION EFFECTS ON WAVE REFRACTION AS DETERMINED BY NUMERICAL WAVE REFRACTION PROCEDURES			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Thesis			
5. AUTHOR(S) (Last name, first name, initial) FARRELL, Charles Augustus, Jr.			
6. REPORT DATE June 1967	7a. TOTAL NO. OF PAGES 62	7b. NO. OF REFS 9	
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)		
b. PROJECT NO.			
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)		
d. <i>Unlimited distribution</i>			
10. AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign government or foreign nationals may be made only with prior approval of the Naval Postgraduate School.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California	
13. ABSTRACT Numerical wave refraction programs permit a detailed study of the trans- formation of wave energy as waves move from deep water to shallow water. By eliminating the subjectivity that is present with hand drawn diagrams the effect of small variations in the initial assumptions and wave conditions can be in- vestigated. The effects on wave refraction of tide level changes and bottom friction are investigated here. It is demonstrated that a uniform increase in water level as would be caused by tidal fluctuations can cause a significant change in the wave refraction pattern for a given nearshore region. A computing procedure is developed to permit numerical refraction programs to account for bottom friction. The reduction in wave height caused by bottom friction depends primarily on bottom slope; this relation is shown in tabular and graphical form.			

14.

KEY WORDS

LINK A

LINK B

LINK C

Wave Refraction
Numerical Analysis
Bottom Friction
Tide level Changes

ROLE

WT

ROLE

WT

ROLE

WT

~~SECRET~~

thesF2293

Tide-level and bottom-friction effects o



3 2768 002 13380 3

DUDLEY KNOX LIBRARY